



The Owl of Minerva:

Governing technology in the quest for sustainability

by

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Statements and declarations

Declaration of originality

This dissertation contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the dissertation, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the dissertation, nor does the dissertation contain any material that infringes copyright.

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Abstract

The Owl of Minerva: governing technology in the quest for sustainability

Companion to the goddess of wisdom, the owl flies at dusk; understanding emerges only at the end of an era. Inspired by insights from both sides of the science and humanities divide, this dissertation surveys the terrain of sustainability before swooping upon our relationship with technology as key to its realisation. It assesses each element of the classic $I=PAT$ equation and determines that humanity's current trajectory is not sustainable. Because effective population (P) policy acts slowly, and because reducing affluence (A) is incompatible with human aspiration, only technology (T) might moderate human impact (I) to sustainable proportions. Building on a comparative analysis of three case studies on chemical herbicides, nuclear power, and robotics and artificial intelligence that identify significant problems with present governance approaches, this study outlines an alternative. Rejecting the attitude that technological '*innovation*' and '*disruption*' are unquestionably good and inevitable, it argues that if sustainability is to be realised, humanity must wrest back control over the technologies we create. Supported by integrity and other measures, this implies going beyond existing approaches to a form of network governance that promises the agility to deal with complex change, while avoiding regulatory capture by commercial and military interests. At the end of this industrial era, there is need for wisdom. Providing that sustainability has priority, that its governance is inclusive, transparent and polycentric, through technology humanity may yet have a long-term future on Earth.

Acronyms

2,4-D	2,4 dichlorophenoxy-acetic acid
2,4,5-T	2,4,5 trichlorophenoxy-acetic acid
4IR	Fourth industrial revolution
AAAI	Association for the Advancement of Artificial Intelligence
ACS	American Chemical Society
AEA	American Economic Association
AFOLU	Agriculture, forestry and other land use
AGI	Artificial general intelligence
AGU	American Geophysical Union
AI	Artificial intelligence
AIS	Automatic identification system (shipping)
AMS	American Meteorological Society
ANS	Adjusted net savings
BJP	Bharatiya Janata Party of India
BWC	Biological Weapons Convention
CFC	Chlorofluorocarbon
CNS	Convention on nuclear safety
CO ₂	Carbon dioxide
COP	Conference of the Parties
CSER	Centre for the Study of Existential Risk
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CWC	Chemical Weapons Convention
DDT	Dichlorodiphenyltrichloroethane
EF	Ecological footprint
EKC	Environmental Kuznets curve
EPA	Environment Protection Authority (US)
EPTA	European Parliamentary Technological Assessment
EPZ	Export processing zone
EROEI	Energy return on energy invested
FAO	Food and Agriculture Organisation (UN)
FHI	Future of Humanity Institute
FLI	Future of Life Institute
FOI	Freedom of information
G20	Group of Twenty (economic forum of 20 major economies)
GAO	Government Accountability Office (US)
GDP	Gross domestic product
GFC	Global financial crisis
GHG	Greenhouse gas
GNP	Gross national product
GPS	Global positioning system
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICTSD	International Centre for Trade and Sustainable Development
IEA	International Energy Agency
ILO	International Labour Organisation (UN)
IPAT	Impact-Population-Affluence-Technology
IPBES	Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change (UN)
IUU	Illegal, unreported and unregulated (fishing)
JFS	Japan for sustainability
LOC	Level of concern
LED	Light emitting diode
LPI	Living Planet Index (WWF)
MCS	Monitoring, control and surveillance
MDGs	Millennium Development Goals

MIT	Massachusetts Institute of Technology (US)
NTFB	Non-timber forest benefits
OECD	Organisation for Economic Cooperation and Development
PDR	Peoples' Democratic Republic
POPs	Persistent Organic Pollutants
PNAS	Proceedings of the National Academy of Sciences (US)
PR	Public relations
R&D	Research and development
RFMO	Regional fisheries management organisation
SDGs	Sustainable Development Goals
STI	Science, technology and innovation (UNESCO)
SWEIT	Species with energy-intensive technology
TAPIC	Transparency, accountability, participation, integrity, capacity.
TINA	There is no alternative (Margaret Thatcher)
TPP	Trans-Pacific Partnership
TRIPS	Agreement on Trade-Related aspects of Intellectual Property Rights
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
UNFSA	United Nations Fish Stocks Agreement
UNGA	United Nations General Assembly
UNHPS	United Nations Secretary-General's high-level panel on global sustainability
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
US	United States
USSR	Union of Soviet Socialist Republics
WANO	World Association of Nuclear Operators
WCC	World Council of Churches
WEF	World Economic Forum
WHO	World Health Organisation (UN)
WIPO	World Intellectual Property Organisation
WWF	World Wildlife Fund

Notes

On style

As recommended by *The Economist* style guide, a tendency to over-capitalisation is resisted.

Acronyms are used sparingly to help make the text more readable.

As Fowler suggests, 'ise' and its variants are preferred to 'ize', if only for the sake of consistency.

'Program' is preferred to the archaic and francophone 'programme', as 'telegram' would have been preferred to 'telegramme' if the opportunity had arisen.

On knowledge

As to what may be known, I am attracted to the view of the entomologist E.O. Wilson (1999, p. 291) that: "all tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics". Deconstructionists and post-modernists, in this view, are mere gadflies, who are nonetheless useful to keep the 'real' scientists honest (Costanza 1999).

On the other hand, I am not convinced that "the workings of social institutions" in particular are tangible phenomena reducible to physics as Wilson asserts. Rather, I think that Bismarck came close to a truth when he said that the making of laws is like the making of sausages: it is better not to observe the process too closely. Although in this he was less invoking a Heisenberg indeterminacy, more its unpleasantness.

And lastly, science is central. But it does not mean that particular scientists are infallible, that methods and results are not influenced by social processes, or that human perceptions of what is important are pure and objective rather than the result of historical and political forces.

Chapter 1. Introduction

For generations, we have assumed that the efforts of mankind would leave the fundamental equilibrium of the world's systems and atmosphere stable. But it is possible that with all these enormous changes (population, agricultural, use of fossil fuels) concentrated into such a short period of time, we have unwittingly begun a massive experiment with the system of this planet itself
— Margaret Thatcher, speech to the Royal Society, 1988.

Riding tigers

Mrs Thatcher and the industrialist Aurelio Peccei, co-founder of the Club of Rome, were once in accord. While Thatcher spoke of “a massive experiment” with the entire planet, Peccei had earlier dictated a message from his deathbed. He said that humanity “must learn how to ride the technological tigers” we have unleashed; if we do not the Earth will become incapable of supporting our species; there will be no future for humankind (Peccei 1984, pp. 41-42). Two centuries of industrialisation, exploding population growth and economic frenzy based on unchecked technologies gave us smog, polluted waterways, toxic waste, soil erosion, deforestation, the extinction of many species, global warming and rising oceans (Westacott 2016). Yet those technologies have also given us the means to check disease and extend life, to connect with each other and to access and apply knowledge in ways beyond the wildest imaginings of the Enlightenment. Our present system of extracting, making, consuming and discarding may be unsustainable, but is not inevitable. This dissertation assesses the factors of sustainability and how we might become more adept at riding Peccei’s tigers.

Is humanity sustainable?

There can be no greater significance than the issue of sustainability for humanity. While ever-narrowing inquiries typify research within all disciplines, this study attempts a breadth commensurate with the importance of the question. If the answer to the question above is in fact an unqualified ‘no’, then ultimately there is no point to any other field of human endeavour. Quantum physics, history, philosophy, engineering, the fine arts, love, capital accumulation – in the longer term, all is for naught and for nothing.

This sustainability issue is just as important for the many life forms fast dwindling at our hand, and more so now than at any earlier time. Yet besides the possible finding of ‘no’ to the question, there are also many variations of an affirmative. Perhaps humanity is sustainable if we adopt a particular policy, if we effect different technologies, if we accept a diminished energy or if global capitalism is better controlled. Perhaps humanity is, in the longer term, already on a sustainable trajectory and this current crisis is just a blip, a speed bump on our digital highway to the future.

The words ‘sustainable’ and ‘sustainability’ in the second decade of the twenty-first century are ubiquitous throughout the Anglosphere, having leapt to prominence around 1980.¹ Businesses aspire to be sustainable. Public strategies require sustainability. No-one supports endeavours that are said to be unsustainable. While the notion of sustainability is both central and contested in several disciplines, as Eriksson & Andersson put it (2010, pp. 59-60), “to understand the true meaning of sustainability, the concept of entropy is necessary”. Entropy is the universal tendency to disorder, in which energy, although conserved in accordance with the first law of thermodynamics,² becomes dispersed and thus less useable over time as it performs work and transitions from higher states to its lowest state: heat. This means that in the long run humanity

¹ According to Google’s N-gram viewer, 2017.

² The first law of thermodynamics is a version of the general law of conservation of energy.

must again adapt to using inexhaustible energy resources as we once did, because in a closed system, the non-renewable stock will run out, just as energy (or states of order) will tend to even out over time in thermodynamics. All energy on Earth ultimately derives from the sun.³

And while ultimately all matter is stardust, and theoretically anything can be constructed from its basic elements, it requires a great deal of energy to change complex material forms. As a result, the extraction of complex forms of matter from the Earth such as metals, chemicals and organic materials will continue as long as humanity foreseeably exists as a civilisation. But minimisation, conservation and re-use of those materials becomes imperative. Otherwise continued consumption and disposal leads only to a material entropy where grains of nickel, calcium carbonate and humus are dispersed beyond recovery over a featureless desert of grey.

In this way, T. S. Eliot's famous phrase from *The Hollow Men* (1925) "this is the way the world ends, not with a bang, but a whimper" has a parallel in the second law of thermodynamics, which states that "any closed system⁴ evolves towards a state of thermodynamic equilibrium" – the state of maximum entropy. If we consider the Earth as a closed system, then the whimper towards the end of its Anthropocene epoch will be an entropy in which any remaining human life will possess minimal degraded capabilities.

However, C. P. Snow's *The Two Cultures* (1959) lecture on the two mutually uncomprehending worlds of science and literature supposes that familiarity with Eliot for a scientist is the equivalent of knowledge of the second law of thermodynamics by a literary intellectual. Both are unlikely. Snow deplores this gulf of understanding between the two fields,⁵ and especially the lack of appreciation of the importance of applied science in addressing the major concerns of his time: "Industrialisation is the only hope of the poor" (Snow 1959, p. 13). Writing during the Cold War, Snow urges a scientific effort of the West to transform the poor societies of "India, Africa, South-East Asia, Latin America and the Middle East" to ameliorate the three menaces that confront humanity: nuclear war, over-population and the gap between rich and poor. While less due to a conscious scientific effort of the West, some of those poor societies have since undergone industrialisation and the threat of nuclear war has arguably diminished. Yet the menaces of over-population and inequality remain. An underlying theme of this dissertation is bridging understandings between cultures and disciplines. The quest for sustainability demands that the sciences and the humanities acknowledge their need for each other.

Consistent with an awareness of the Earth as a linked, closed system rather than a limitless resource (Boulding 1966, Buckminster Fuller 1969, Commoner 1972, Holdren & Erlich 1974, Lovelock 1979) that has developed since Snow's identification of these threats, overpopulation and inequality still imperil not only humanity, but all species that form life on Earth. The classic I=PAT equation, meaning human environmental impact is a product of population, affluence and technology, has been used to identify the key relationships that govern sustainability for most of the ensuing six decades. Population alone is not the only basic determinant of our effect on the planet. Unlike other species, our impact is greatly amplified by the factors of affluence and technology. This dissertation uses the equation to structure its analysis of sustainability. However,

³ This includes fossil fuels that are due to photosynthesis, radioactive materials that came from solar matter, wind that is caused by solar radiation differentials and the tides that result from the orbits of the Earth and the moon about the sun.

⁴ There is an important difference between a 'closed' and an 'isolated' system in thermodynamic theory, which is discussed later in this dissertation.

⁵ Although DiMaggio (2015, para. 2) asserts "that the era of the "two cultures" (Snow, 1959) is over" based on his experience as a social scientist working with computer scientists, finding instead of chasms, only "modest differences in orientation" due to their respective intellectual traditions.

the relationship, between these factors, originally formulated by Erlich (1968), is not entirely straightforward. Neither is the meaning of each element.

The IPAT relationship remains the most coherent summation of factors that relate to sustainability. However, the meanings of the latter two factors especially – A (affluence) and T (technology) — have changed considerably since its original conception (Chertow 2000). Also, there is no direct empirical relationship between affluence or technology and environmental impact. Rather, in line with Kuznets (1955), there is evidence that the environmental impact of at least some pollutants first rises with increasing affluence, then falls as wealth further increases (World Bank 1992). Some technologies benefit the environment. Some cause outright harm.

Moreover, the measurement of affluence itself is problematic. It is usually assumed to be measurable by gross domestic product (GDP), given that production equates to consumption, which is determined by affluence. However, GDP and similar measures do not quantify all aspects of production and consumption. What is consumed can affect the environment as much as how much is consumed, and consumption of intangibles is increasing.

The interaction of technology with the environment may be positive as well as negative. In the original IPAT equation, Erlich (1968) postulated carbon dioxide emission as a cipher for technology use, as then technological density and industrialisation emitted more carbon dioxide. Certainly this is still essentially true of recently industrialised economies such as China and increasingly India, where coal-fired power stations and secondary industries continue to be built at an astonishing rate and where air pollution is legendary. However newer technologies such as solar cells emit no carbon dioxide in use. Digital technologies facilitate analysis and the acquisition of knowledge, and also emit little. Sensors and meteorological computer models help mitigate the effects of weather through accurate prediction. And contraception technologies negatively effect population and thus contribute to a reduced environmental impact.

This dissertation initially explores the nature of human sustainability and its dimensions through the IPAT lens. It examines how perceptions of the variables that compose it have changed, their interrelationships and how the concept might guide policies that lead to a more sustainable world. Because each of its variables relate to different fields, including the social, physical and life sciences as well as the humanities, an interdisciplinary approach is used to investigate this concept and its related public policy.

Now, however, we have the advantage of being able to look backwards in time to the beginnings of the modern environmental awakening, as well as forwards to where our fate may lead. That awakening was directly related to the accelerating impact of new technologies after the Second World War (Carson 1962, Commoner 1972, Steffen et al 2011), as well as to the accumulation of technologies that began with the Industrial Revolution. Half a century since that environmental awakening, innovation and still newer technologies are exploding into diverse realms, based on digital computing, new means of data capture and analysis capabilities on a scale unimaginable only a generation earlier. The relationship between humanity and technology is symbiotic. Our technologies affect us as much as we affect them and the relationship is intensifying. It is to this bond that this dissertation turns as the only practicable policy area whereby sustainability might be effected in the medium term.

Research question

The research question is in two parts: (1) *Having regard to the key factors affecting the impact of humanity on the Earth, is our current trajectory sustainable?* (2) *Of those factors, how important is technology to sustainability, and how might its governance best be approached?* The former

part attempts to assess how close we are to disaster and the main factors driving it. The second part, focuses on technology in particular and describes both weaknesses in, and implied reforms to its governance that promise a long-term future for our species, and for the remaining creatures with which our world is shared.

Thesis

That while the evolving discourse surrounding sustainability involves patterns of paradox and contradiction, these are overridden by our dependence on technologies that greatly amplify human impact such that it is not sustainable. Because neither rapid population reduction nor declining affluence are practical policy goals, the quest for sustainability demands a conscious re-fashioning of our relationship with technology that centers on energy intensity, its impact on other life forms, and its capacity to dematerialise the effects of our existence. This implies measures that focus on technology governance with sustainability as a predominant principle.

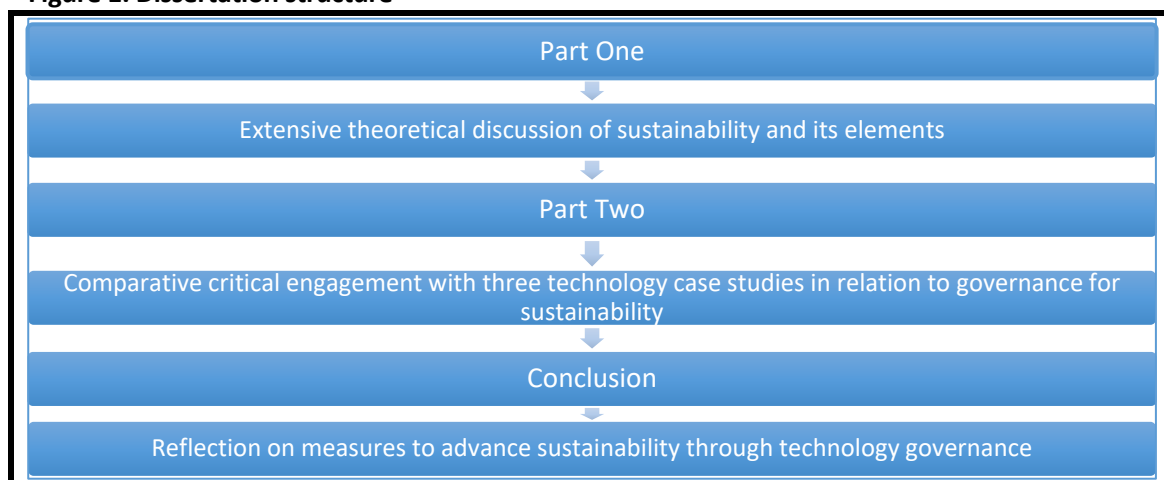
Approach

Taking Snow (1959) as an inspiration, the approach is interdisciplinary. It consists of a broad review of the concept of sustainability spanning relevant literatures, including analysis of elements of the IPAT relationship, with particular reference to technology. Technological regimes at the state and global level are then assessed against the criteria of good governance. The dissertation then analyses three representative case studies of major technologies – the herbicide glyphosate, nuclear electricity, and robotics and artificial intelligence. The case studies are aimed at detecting strengths and weaknesses in their governance, with a view to the identification of policies that show promise in the pursuit of sustainability. As well as the literature review and comparative case studies, its methods involve discussions with leading scholars and practitioners as well as analysis of insights from disciplines including anthropology, astrobiology, biology, ecology, economics, geography, history, paleontology, philosophy and physics, together with politics and public policy theory.

Structure

Consistent with the research question, the structure is in two parts. Part One is an analysis of human sustainability tied to each element of the IPAT equation as separate chapters, based on an extensive literature review. Part Two singles out our relationship with technology as an issue of governance. Three case studies of major technologies are assessed as separate chapters, and their governance strengths and weaknesses identified and alternatives explored. The conclusion reflects on the global measures involving technology that may advance sustainability, affecting its governance, both structural and institutional (see figure 1 below).

Figure 1. Dissertation structure



Part One. Sustainability and its elements

Chapter 2. The concept of sustainability

*This is the dead land
This is cactus land
Here the stone images
Are raised, here they receive
The supplication of a dead man's hand
Under the twinkle of a fading star*

– TS Eliot, *The Hollow Men*

Eliot's image of a lifeless Earth looms as one reflects on what has happened to our planet home in recent times. By contrast with this representation, a more hopeful world is alive, vibrant, interconnected: a sustainable one. The concept of sustainability is recent, yet concerns about it have been with us for millennia. It encompasses all resource extraction, production and consumption of goods and services. It includes how waste is treated and our impact on other life forms on which we depend, or which are part of the one biosphere that we share. It encompasses and is yet distracted by 'climate change' as it was once distracted by 'the population explosion'. Sustainability is simply human activity that might continue indefinitely.

This Part One of the dissertation is a broad appraisal of the concept of sustainability and its components, with a view to what may be practically feasible. It is structured according to the classic I=PAT relationship: human impact (I) is a product of population (P), affluence (A) and technology (T). Each of these elements form the following chapters 3, 4, 5 and 6. Based on this investigation, chapter 7 assesses the directions that show most promise in realising a more sustainable humanity.

This chapter 2 sets out key aspects of the sustainability concept, especially historically, scientifically and politically. It is argued that the notion is important within all such spheres and that its pursuit, ultimately through politics, depends on the development of a compelling narrative to support its realisation.

The notion of long-term global sustainability has yet to fully enter widespread consciousness; many still operate with a nineteenth century mindset of a nature without limit and frontiers of civilisation to be 'opened up' and exploited. By contrast, reality is that nature clearly has limits and there are no more frontiers that can be exploited without consequence.

The early Christian, Tertullian (1951 [c. 200 AD]), observed that humans were "burdensome to the world" nearly two thousand years ago, and instances of unsustainable practices have increased throughout history. Lead pollution was evident in ancient times (Hong et al 1994). The burning of 'sea coal' in London became increasingly obnoxious during the Middle Ages (Chew & Kellaway 1973, no. 617). Timber harvesting in England and much of Europe became unsustainable during Elizabethan times (Van der Zee 2013). The volume of sewage in Victorian cities led to epidemics before the imperative of reform (Snow 2008). The Romantics were dismayed at the price nature paid for the Industrial Revolution. In the United States (US), the Sierra Club and national parks were established in the late nineteenth century in reaction to a fast diminishing natural world. The 1930s 'dustbowl' tragedy showed the importance of sustainable agricultural practices. In the 1940s and 1950s, the many deaths from air pollution in Donora, Pennsylvania and in London helped spur more sustainable industrial practice, at least in the US and UK. Fatalities and deformities from heavy metal accumulation in Japan in the 1960s finally led to better controls over following decades. Asbestos and lead poisoning has been curtailed in rich countries since the late twentieth century and emissions of ozone

depleting substances have lately been limited by near universal international law, because their use was unsustainable. Sustainability implies minimal harm to both humans and the biosphere. It is a self-evident imperative where they intersect.

Although human awareness that demanding no more than the environment can supply is historically and geographically age-old (Matson, Clark & Andersson p. 2), contemporary anxieties about sustainability date from the 1960s when Rachel Carson's *Silent Spring* (1962) and the Erlichs' *The Population Bomb* (1968)⁶ were published. Carson highlighted the perils of synthetic pesticides while the Erlichs made public the threat of runaway population growth. In 1969 a new mandate for the International Union for the Conservation of Nature (IUCN) referred to management of 'air, water, soils, minerals and living species including man, so as to achieve the highest sustainable quality of life' (Adams 2006, p. 2).

However, the Massachusetts Institute of Technology (MIT) report for the newly formed Club of Rome, *The Limits to Growth* (Meadows et al 1972), first showed the profound effects of continued exponential consumption on a finite planet, using computer modelling. Graham Turner's 2014 article *Is Global Collapse Imminent?*, which compares the report's predictions to reality, suggests that the original *Limits* was remarkably accurate in forecasting patterns of population, economic growth and resource use in the four decades since it was written.⁷ Pointedly, he concludes that if the unsustainable 'business as usual' trajectory continues, then global collapse within the next decade or two is imminent (Turner 2014, p. 3).

Prompted by the *Limits* projections, the new concept of "sustainability"⁸ was first articulated at a World Council of Churches (WCC) meeting involving scientists, theologians and economists in Bucharest in 1974, at which the "intolerable strain on the Earth's resources" was discussed in the context of science, technology and human development. According to David Hallman's later WCC report:

What emerged out of the [1974] Bucharest discussion on the role of science and technology in the development of human societies was the articulation of a concept called "sustainability" - the idea that the world's future requires a vision of development that can be sustained in the long run, both environmentally and economically. The awareness of the need to link socio-economic justice and ecological sustainability has been a recurring theme within the ecumenical community and has been a gift to the broader global community (Hallman 2002, para. 8).

These early prophecies of peril resulted in measures aimed at curbing excesses, especially in the industrialised West, as well as the creation of global mechanisms relating to the environment and sustainability. During the 1980s these measures included the *World Conservation Strategy: Living Resource Conservation for Sustainable Development* (1980), the *World Commission on Environment and Development* (1983), the *Montreal Protocol on Substances that Deplete the Ozone Layer* and the Brundtland report *Our Common Future*, both 1987. Since that flurry of activity, measures relating to sustainability noticeably faltered and narrowed. There was the Kyoto protocol of 1997, the stalemate of Copenhagen in 2009 and the diluted extension of Doha in 2012, all of which attempt to forestall climate change by

⁶ Both Anne and Paul Erlich were the original authors, although the publisher decided to list only Paul.

⁷ Specifically, Turner refers to "population, industrial capital, pollution, agricultural systems, and non-renewable resources" (Turner 2014, p. 5).

⁸ Although the notion of 'sustainable yield' emerged with scientific forestry in Germany during the eighteenth century (Worster 1993, p. 145).

limiting greenhouse gas emissions. The Paris emissions agreement of 2015 yet stood out as an important step forward, at least as far as global warming is concerned.

There have also been the Rio (1992) and follow-up Earth Summits (*Rio+5*, *+10* and *+20*) that concerned conservation, poverty reduction and empowerment. There were the eight Millennium Development Goals (MDGs) 2000-2015 that included an eleventh hour goal seven, to *ensure environmental sustainability*.⁹ This goal included targets for biodiversity loss, deforestation, fish stocks and water quality as well as emissions. However, the focus of the MDGs was more on other goals, especially poverty reduction, health and gender equality. More importantly, the MDGs were targeted at developing countries – there was no goal seven that applied to the industrialised world, nor in practice to China. At least the Sustainable Development Goals (SDGs) that replaced the MDGs from 2016 do involve targets for rich countries; thus for the first time wider sustainability is recognised as a global problem for global action.

Empathy and entropy

Beyond these historical aspects of the concept, there is the anthropological and the planetary. While it has been observed that no social animal is guided by the welfare of the entire species to which it belongs, humans are a potential exception. Originally tribal and territorial, our species first conceived of ‘universal orders’,¹⁰ when the entire human race could be imagined as a single unit about three thousand years ago. This meant that everyone was potentially ‘us’. There was no longer ‘them’ (Harari 2014, pp. 171-172). Since then, despite many setbacks, the overall historical trend has been towards greater global unity. Around the end of the last ice age there were thousands of autonomous human worlds on the planet. Five hundred years ago most people lived in the single Afro-Asian landmass with limited cultural and economic interconnections. Now there is only one world. Harari (2014, pp. 167-168) observes that Tasmania, with the arrival of British settlers from Sydney in 1803, was the last autonomous human world to be brought under the dominant Afro-Asian, (in this case, European) sphere of influence.¹¹

This impinges on the notion of moral progress, which means “including ever more people (or beings) in the group of those whose interests are to be respected”, illustrated by Hierocles, the second century Stoic philosopher, who described our relationships as a series of concentric circles radiating from the self, then the immediate family, the neighbourhood, the state and so on (Klein & Cave 2015). It further links with the notion of the ‘land ethic’ by which we are bound to respect our biotic community: water, animals, plants and the soil (Leopold 1977 [1949]).

In *The Empathic Civilisation*, the US social theorist Jeremy Rifkin takes this idea further and conceives “a grand paradox”. He suggests that the whole of history is a struggle between the polar forces of empathy and entropy. Just as we have extended empathy to all of humankind, the industrialised infrastructure needed to accomplish that interconnectivity “is running up against a rapidly accelerating entropic juggernaut” in “climate change and the proliferation of

⁹ According to its lead author, Mark Malloch Brown of the UNDP, goal seven was a last-minute inclusion due to a chance meeting in the corridor he had with “the beaming head of the UNEP”, even as an earlier version had already been sent to print. Brown says “a terrible swearword crossed my mind when I realised we’d forgotten an environmental goal ... we raced back to put in the sustainable development goal” (Malloch-Brown in Tran 2012).

¹⁰ Harari proposes three such universal orders: monetary, imperial and religious.

¹¹ While New Zealand was settled by Europeans a little later – in 1814 – the Maori ended its autonomy at the end of the Polynesian expansion several hundred years earlier.

weapons of mass destruction". This self-destruction can only be averted by developing what Rivkin terms a "biosphere consciousness", a collective sense of affiliation with the entire biosphere and its systems (Rivkin 2009, p. 21).

Indeed, it has been observed that humanity is now involved in a "world-wide conversation about the issues of human longevity on Earth", but as yet a satisfactory vision of sustainability has not been framed. Sustainability is still often regarded as just one of many issues - rather than the "linchpin that connects all the other issues" (Orr 2006, p. 266). In this vein, one pithy statement about sustainability is from the former British ambassador to the UN, Sir Crispin Tickell, who speaking of sustainable development, described it as "treating the Earth as if we intended to stay" (Tickell 2013).

Alternatively, the issue of sustainability can be seen from the viewpoint of the Earth itself, rather than from the position of humanity. James Lovelock is associated with this idea that goes beyond the Anthropocene and dynamic Earth systems approaches.¹² *Gaia* – the Greek goddess of the Earth – envisages a planet that is itself "alive, in the same way that a gene is selfish". The Earth is "a self-regulating entity" and able to dispense with those that threaten life – including humans (Lovelock 2000 [1979], p. ix). The atmosphere is a biological construction, not living, but like a bird's feathers or a wasp's nest, an extension of a living system designed to maintain a chosen environment (Ibid, p. 9).

The term 'Gaia' was suggested to Lovelock by his neighbour, William Golding, the 1983 Nobel laureate for literature (Lovelock 2000 [1979], vii). The concept reputedly enraged scientists such as the evolutionary biologist Richard Dawkins, because the strong form of the hypothesis presupposes a singular member (the Earth) of a separate species that has evolved without natural selection. However, it became popular with the wider public and those scientists of less rigid disposition who saw it as more of a metaphor. Lovelock developed the idea while working for the Jet Propulsion Laboratory in California, when pondering the quest to discover life on other planets. He reasoned that all life is anti-entropic. Therefore, evidence for life would be found in signs of anti-entropic processes.

Thus sustainability on Earth is linked to a maintenance or increase of life, a conservation or lessening of entropy. This notion has profound consequences. For example, a loss of biodiversity points to a reduction in sustainability. A loss of populations within species points to less sustainability. Any factor on which diverse life forms depend, such as forests or seas or entire ecosystems, if degraded, means that sustainability has been lost. This general concept of sustainability is used throughout the rest of this dissertation. Its relationship to the term 'sustainable development' is discussed later in this chapter.

Industrialisation

Predominating these considerations is the notion that human impact on the planet, now clearly a matter of dire concern, is largely the result of the industrialisation that began only within the past 200-odd years. This industrialisation was and still is based on the extraction and burning of coal, oil and gas. Even the icons of modernity – mass production, grid electricity, the telephone, the car, chemicals, plastics – derive from these fossil substances. The problem is not only that the amounts of these materials are limited, but more immediately that their extraction and use is harmful to the biosphere on which all life depends.

¹² Although Lovelock acknowledges that the idea of a living Earth system originated with the 'father of geology', James Hutton, in a 1785 lecture (cited in Young 1991, p.122).

Coal, oil and gas are all forms of stored energy from the sun, the result of ancient plants and forests that grew in the oxygen-rich atmosphere of the carboniferous period, 300-350 million years ago. Since the Industrial Revolution we have been raiding that stored sunlight and now face the consequences. Either the storehouse will be emptied or the environment will be permanently altered, or both.

Over the past thousand years, global average temperatures have varied less than one degree Celsius (Wilson & Piper 2010) but show a sharp rise after the 1960s. But while the current widespread concern about 'climate change', or 'global warming' and the earlier term 'greenhouse effect' has become part of global consciousness only within the past twenty years or so, one of its more obvious effects, that of melting ice, was known to popular science much earlier. Rachel Carson's lesser known 1952 classic *The Sea Around Us* describes in some detail the opening up of the Arctic Sea due to reduced in ice cover from the early twentieth century:

We are witnessing a startling alteration of climate...a definite change in the arctic climate set in about 1900, that it became astonishingly marked about 1930, and that it is now spreading into sub-arctic and temperate regions...in 1932, for example, the *Knipowitsch* sailed around Franz Joseph Land for the first time in the history of arctic voyaging...the season when pack ice lies about Iceland became shorter by about two months than it was a century ago...drift ice in the Russian sector of the Arctic Sea decreased by a million square kilometres between 1924 and 1944 (Carson 1952, pp. 183-184).

Carson also shows that awareness of global glacier melt, too, was evident quite some time ago. She lists a "catastrophic" decline in glaciers of the Alps as well as those of Norway, the North Atlantic coast and Alaska "during the last decades".¹³ Further:

Northern glaciers are not the only ones that are receding...the glaciers of several East African high volcanoes have been diminishing since they were first studied in the 1800s – very rapidly since 1920 – and there is glacial shrinkage in the Andes and also in the high mountains of central Asia (Carson 1952, p. 186).

Yet while the effects of global warming are clear and "the long trend is toward a warmer Earth" (Ibid, p. 187), Carson is wary of pointing to a definitive cause. Changes in ocean currents, tidal movements, natural post-Pleistocene warming, and an increase in solar activity are all countenanced. Anthropogenic causes are not.

Today that main cause is, according to scientific consensus, clear. It is anthropogenic and due to industrialisation. Palutikof et al (2013 p. 4) propose a three dimensional relationship between the costs of climate change impact, mitigation and adaptation. Greater resources put into either or both mitigation and adaptation result in lower impact costs whereas fewer resources put into either or both result in higher impact costs. These impacts include not only short term disasters such as stronger hurricanes, but also long term increases in salinity, loss of water table, droughts, crop failures, sea level rise and biodiversity decline – all of which imply loss of sustainability.

Even the venerable author of *The Population Bomb*, Paul Erlich, is more than concerned about the climate: "Climate change may be the most serious issue there is, another may be the

¹³ The 1920s.

toxification of the planet” (Erich 2009). US President Barack Obama is curt about what this means for fossil fuel extraction: “We’re not going to be able to burn it all” (cited in Rusbridger 2015).

Industrialisation affects sustainability well beyond the dimension of climate change, however. Its effluents may directly destroy life forms and its resource extraction may destroy whole ecosystems. And there are many views on its remedy. John Dryzek in *The Politics of the Earth* (1997) identifies eight different discourses that counter the long-dominant Promethean paradigm of industrialism, by which unlimited growth is both assumed and approved. These eight alternative discourses he classifies as either ‘radical’ or ‘prosaic’ and either ‘reformist’ or ‘imaginative’, as outlined in figure 2 below:

Figure 2. Alternative environmental discourses

	Radical	Reformist
Prosaic	Survivalism <ul style="list-style-type: none"> Survivalist (challenges limitless growth but not societal structure, e.g. ‘<i>Limits to Growth</i>’) 	Environmental problem solving by: <ul style="list-style-type: none"> Experts (administrative rationalism) ‘the people’ (democratic pragmatism) the market (economic rationalism)
Imaginative	Green radical <ul style="list-style-type: none"> Green romanticism Green rationalism (includes social ecology, deep ecology, ecofeminism and environmental justice movements) 	Sustainability <ul style="list-style-type: none"> Sustainable development Ecological modernisation or ‘ecomodernism’ (seeks to resolve environmental and economic conflict and ignore limits)

Source: based on Dryzek 1997

The *survivalist* discourse is radical because it challenges the notion of limitless growth, yet it is prosaic because its solutions, such as more rational control, are within the constraints of industrialism. The three *environmental problem-solving* discourses are both reformist and prosaic because they all accept industrialism and their solutions are adjustments to the status quo. They differ according to agency for control of environmental policies – experts, ‘the people’ or the market. The two *green radical* discourses – green romanticism and green rationalism – are both radical and imaginative. These discourses reject the structure of industrial society and imagine radically different societies and environmental relationships. They include strands of the social ecology, deep ecology, ecofeminist and environmental justice movements. Lastly, the two *sustainability* discourses are both reformist and imaginative. They seek to dissolve the conflict between environmental and economic values and seek to minimise the notion of limits.

When considering the politics of sustainability, it can be an advantage to understand what sort of discourse is acceptable. In part, this depends on how the concepts are ‘framed’. For example, people relate more to identity and values rather than facts and self-interest (Lakoff, 2004); the tendency of sustainability to be couched as a bio-physical systems issue rather than a social issue makes it less likely to be addressed with the policy urgency it deserves (Hackman et al 2014, p. 655).

In this vein, Alex Steffen (2009) makes the framing rather simpler. He divides environmental sustainability into three shades of green. *Light greens* see the issue as one of personal responsibility and individual lifestyle, *dark greens* see a radical change in economics and

consumption as the only answer to continuing destruction, while his preferred *bright greens* favour technological innovation and regulation as the best way to lighten human impact on the planet, as shown in figure 3 below.

Figure 3. Three shades of green



Source: Steffen 2009.

A fourth category are the greys – those who deny that there is a problem and promote business as usual. For practical reasons, this dissertation concludes that a form of bright green framing is most apt.

The IPAT relationship

This sort of framing emerged from earlier intense debates within the environmental movement. The classic Impact = Population × Affluence × Technology (I=PAT, or IPAT) relationship is directly related to sustainability as it conceives the dimensions of human impact on the biosphere. Where that impact exceeds the capacity of the biosphere, it is not sustainable. However, the formulation has been interpreted quite differently depending on who has referred to it over its half-century of existence.

The IPAT equation was developed during the late 1960s as a result of debates between the biologist and ecologist Barry Commoner (1917-2012), biologist and demographer Paul Ehrlich (b. 1932) and physicist John Holdren (b. 1944), who was President Obama's White House advisor on Science. Ehrlich and Holdren argued that of each of these three factors, the population factor is most important. Erlich and his wife Anne, who co-authored the 1968 best seller, *The Population Bomb*, had visited India as students and had been shocked at the apparent overpopulation and widespread poverty. It is likely that this experience led them to believe that overpopulation was the main cause of poverty and of environmental impact. Commoner, however, argued in *The Closing Circle* (1971) that environmental impacts (especially pollution) were caused primarily by changes in production technology following World War II, because these impacts far outweighed any population increase, especially in the US. Erlich and Holdren opposed this and focussed their argument increasingly on the population explosion and its consequences. Erlich has continued to hold this view since:

While the basis of climate change was known towards the end of the nineteenth century everybody who didn't need to take off their shoes to count to twenty, knew that population is part of the problem fifty years ago (Erich 2009).

However, it was Erlich and Holdren who first wrote:

Pollution can be said to be the result of multiplying three factors; population size, per capita consumption, and an 'environmental impact' index that measures, in part, how wisely we apply the technology that goes with consumption (cited in Commoner et al 1971, p. 3).

Commoner attempted to re-interpret this more precisely in 1972 as:

$$pollution = (population) \times (production\ per\ capita) \times (pollution\ emission\ per\ production).$$

This version is at least logically valid, since the above and below the line 'populations' (or 'per capita') and 'productions' cancel each other out, leaving *pollution = pollution emission*. This was then re-written by Erlich as the now familiar I=PAT equation (Chertow 2000, p. 19). However, in 1974 Erlich and Holdren (1974, p. 288) again re-interpreted this as:

$$environmental\ disruption = population \times consumption\ per\ person \times damage\ per\ unit\ of\ consumption.$$

Erlich and Holdren saw the variables as interdependent, whereas Commoner viewed them as independent of each other (Chertow 2000, p. 19). The significance of this difference is that the former pair wanted population as the central culprit, thus population affected both affluence and technology in producing a final impact. Whereas, Commoner believed the new post-war technologies to be the culprit, irrespective of population and affluence. In this respect, he advanced considerable evidence that new technologies had environmental impacts orders of magnitude beyond the other two factors (Commoner 1972 and 1990).

The 'I' in the equation (or environmental impact) is at first regarded as simply *pollution*, whereas later it became *environmental disruption*, a much wider concept that, for example, may include land clearing, loss of habitat and species extinction as well as pollution alone. Further, technology (T) is equated with "*pollution*", or "*pollution per unit of production*", or else "*damage per unit of consumption*", which tends to assume the damaging and heavily polluting industrial technologies of the mid-twentieth century. The possibility that some technologies might reduce environmental impact is not countenanced. Lastly, affluence is equated with either consumption or production depending on the formulation, but its impact depends on how it is measured.

While the IPAT formula was originally developed by life-scientists¹⁴ as distinct from other groups, investigating issues surrounding it have also been conducted by social scientists, in parallel, but separately and "often antagonistically" (Dietz & Rosa 1994, p. 277). For example, in *The Wealth of Nature*, US historian Donald Worster (1991, pp. 7-8) outlines examples of unsustainability based on material "revolutionary forces" such as demography, technology and energy embodied in the "effortless industrialism" that supplies almost limitless goods to the affluent. These 'forces' are close to the IPAT concept but describe a more detailed modern

¹⁴ Although John Holdren studied aeronautics and physics, he was Professor of Environmental Policy at the Kennedy School of Government at Harvard.

world. Still, Worster suggests the real cause of environmental destruction in modern America is culture – driven by an attitude of human innocence in an Eden where all is fruit for the picking.

In 2000, the Australian engineer, Sharon Beder (2000, p. 2), advanced the IPAT formula as:

I: environmental impact = P: number of people × A: resource use per person × T: environmental impact per unit of resource used.

This is again slightly different and focuses on resource use rather than pollution emission as the key factor.

The Kaya identity is closely related to the I=PAT equation. But while the I=PAT equation is more general and can describe a more abstract 'impact', the Kaya identity describes the impact of human activity specifically on carbon dioxide (CO₂) emissions. It was developed by Japanese energy economist Yoichi Kaya in his book *Environment, Energy, and Economy: strategies for sustainability* arising from the 1993 Tokyo Conference on Global Environment, Energy, and Economic Development. The Kaya identity differs from IPAT, having four rather than three variables:

global CO₂ emissions = global population × gross world product per global population × gross energy consumption per gross world product × global CO₂ emissions per gross energy consumption.

Like the I=PAT equation, whereby (in some versions) pollution ultimately equals pollution, variables above and below the divisor lines cancel each other out, so that its mathematical validity is demonstrable. One limitation of this equation is that it does not account for the direct release of carbon dioxide by deforestation through burning, nor the loss of the carbon sink also due to forest destruction, because it assumes carbon dioxide is directly linked to energy consumption. While carbon dioxide output rose noticeably with the Industrial Revolution and its increasing consumption of fossil fuels, this was inter-related with temperate deforestation across Europe, North America and Australasia during the same period, which also saw considerable growth in world population and production. The Kaya equation therefore does not encompass the full impact of carbon emissions.

In his 2010 article, *Energy, Economic Growth and Environmental Sustainability*, Steven Sorrell discusses the IPAT identity in relation to energy and resource efficiency. Again the terms are subtly twisted. In particular, technology (T) becomes 'performance' or 'efficiency':

Over the long term, continued economic growth can only be reconciled with environmental sustainability if implausibly large improvements in energy and resource efficiency can be achieved. This point is easy to demonstrate with the $I = P \times A \times T$ equation, which represents total environmental impact (I) as the product of population (P), affluence or income level (A) and technological performance or efficiency (T)...The decoupling strategy seeks reductions in T that will more than offset the increases in P and A, thereby lowering I (Sorrell 2010, p. 1795).

Elizabeth Kolbert (2011) and (Will) Steffen et al (2011, p. 6) use the I=PAT equation to visualise the current state of human impact on the planet over time, relative to both 1900 and 1950. If conceptually valid, the acceleration of the impact since 1950 is staggering. However, while still considerable, the impact is arguably much less than portrayed in the illustration that

accompanies both articles because 'population' is double-counted in both 'affluence' and 'technology'.

A more recent article (Brondizio et al 2016, p. 2) discussing the 'Anthropocene' concept suggests that because it represents a "state change" in the "interdependent social-ecological" Earth system, the concept is different "from earlier ideas of human pressures" due to "a combination of population growth and economic and technical change, having an impact on natural systems, whether local or global". Yet, whether the concept does in fact differ much from what is still clearly a reformulation of IPAT, may be less important than the authors' call for more collaboration across disciplines to help reach sustainability.

The feminist critic, Patricia Hynes, believes that the IPAT identity is so entrenched that it is "like a mental boxing ring", that both its advocates and its critics debate within it, rather than from a critical outside position (Hynes 1993, p. 3). Its combination of simplicity and universality makes the relationship particularly hard to escape from. In Hynes' view, the relationship lacks any dimension of environmental or social justice, especially for the lowest quintile of humanity whose only goal is daily survival (Ibid, pp. 7-8). She goes on to suggest that environmental justice means that women's health should be an end in itself, rather than a means to reach population goals, and that the general education of women and girls, as well as the education of men and boys in peace studies, non-violence to women and environmental management are some of its public policy implications (Ibid, pp. 51-52).

Jeffrey Sachs (2008 p. 6) does begin to look at justice issues, while at the same time factoring in only some of the elements of the IPAT relationship. He outlines four main causes of the 'unsustainability crisis' – human pressure on ecosystems and climate, rapidly rising population especially in areas least able to cope, the poverty of one sixth of humanity unrelieved by global economic growth, and paralysis of global problem-solving due to cynical, defeatist attitudes and inadequate institutions. Sachs is politically connected, at least within the US and UN, and was influential in the creation of the Millennium Development Goals (MDGs). However, it is intriguing that he does not mention technology in relation to sustainability. It is as if he is concerned with the 'I' (impact), the 'P' (population) and the 'A' (poverty in this case), but not at all with the potential of the 'T' (technology) as either a positive or negative factor.

Yet the original concept lingers still at high levels. The ghost of the IPAT relationship lurks within the Intergovernmental Panel on Climate Change (IPCC):

Without additional efforts to reduce GHG emissions beyond those in place today, global emission growth is expected to persist driven by growth in global population and economic activities (high confidence) (IPCC 2014d, p. 81)).

The IPAT relationship remains central to issues of sustainability. As an overarching concept it can constrain debates but it also disciplines them and it has inherent flexibility. It tells us, for example, that to reduce human impact we need to moderate population, reconsider the nature of affluence and develop technologies that enhance rather than degrade life systems. It is at least a well-trodden start line, a place to begin. For these reasons the structure of part one of this dissertation follows its formulation.

Images

Formulae can be uninspiring, however. The potency of a concept can rather depend on its imagery. It is often asserted that the first photographs of the entire planet by the Apollo moon missions in the late 1960s led to a change of consciousness, a new awareness of the limited

and fragile nature of the biosphere that we all occupy. Certainly the new 'blue marble' image of the entire planet was used to support environmental causes and a new environmental awareness became widespread at around the same time.¹⁵ However, such an effect was predicted nearly two decades before. In 1950 the Cambridge astronomer, Fred Hoyle, predicted that:

Once a photograph of the Earth, taken from outside, is available, we shall, in an emotional sense, acquire an additional dimension...once let the sheer isolation of the Earth become plain to every man whatever his nationality or creed, and a new idea as powerful as any in history will be let loose...it must increasingly have the effect of exposing the futility of nationalistic strife (Hoyle 1950, p. 8).

While perhaps over-optimistic about the demise of "nationalistic strife", Hoyle's view has validity still. Nonetheless, the 2013-2014 President of the American Association for the Advancement of Science, Phillip Sharp, believes that the power of the blue marble is less than Hoyle had hoped:

our awareness of the global nature of major problems facing our planet is relatively new and demands global responses for which neither the scientific community nor the general public is well-prepared (Sharp 2014, p. 1468).

The issue now is more how to act on that awareness, rather than contesting the degree of impact our species is having on the biosphere. In that vein, Sharp is more positive. A microbiologist, he thinks that "ecosystem engineering" will reduce damage and restore ecosystem functions through analysis of micro-organisms using DNA sequencing. This is a prominent example of techno-optimism, the view that technology can be used to save rather than destroy our environment, which is discussed later in the *technology* chapter. More broadly, he suggests that we need to converge across disciplines (life, physical, social and engineering sciences) as well as between research and its implementation through entrepreneurship (Ibid, p. 1471).

This echoes the economist Kenneth Boulding, who in anticipation of CP Snow, in 1956 drew attention to the increasing development of 'knowledge silos', whereby physicists only talk to physicists and economists to economists. He feared that this "assemblage of walled-in hermits" who are mutually unintelligible would slow the growth of knowledge. However, he is encouraged that as a result there were then an increasing number of 'hybrid disciplines' such as social psychology and astrophysics. Interestingly, he also draws attention to the possible re-birth of political economy, which he said had died prematurely in the mid nineteenth century (Boulding 1956, p. 129).

The polymath inventor Buckminster Fuller was of a similar frame of mind when writing his *Operating Manual for Spaceship Earth*:

Of course, our failures are a consequence of many factors, but possibly one of the most important is the fact that society operates on the theory that specialisation is the key to success, not realising that specialisation precludes comprehensive thinking. This means that the potentially-integratable-techno-economic advantages accruing to society from the myriad specialisations are not comprehended integratively and therefore are not

¹⁵ For example, the counter-cultural *First Whole Earth Catalogue* was published in 1968, with its front cover showing an image of the Earth taken from space, which reputedly its editor had campaigned for NASA to release.

realised, or they are realised only in negative ways, in new weaponry or the industrial support only of warfaring (Buckminster Fuller 1969, p. 3).

While Sharp and his predecessors appear to presume that capitalism is a friend of the environment and sustainability through its emphasis on technological innovation, Boulding and Snow have reservations in that the overspecialisation it engenders means sustainability will be far more difficult to achieve. On the other hand, however, Marshall McLuhan and Robert Logan (1976, p. 26) assert that Snow had “naïve hang ups” about increasing specialisation, because, “in the electric age there can be no more monopolies of knowledge”. Professor Logan confirms the passage means that barriers between different disciplines are reduced by the electric technologies of the ‘global village’.¹⁶ This is discussed later in chapter 5 on *affluence*.

Before Buckminster Fuller’s *Operating Manual*, Kenneth Boulding was also one of the first to identify the Earth as a “spaceship” (Boulding 1966), meaning a self-contained economy with physical limits as opposed to an endless frontier that could be exploited indefinitely without ecological consequence. In this way, it is relevant to consider the defining characteristics of artificial spaceships that are designed to transport people through the cosmos. Even the early orbital and lunar spaceships had to provide resources and environments that supported human life, including air, water, food and means of waste disposal. Longer voyages such as the Mars mission, possibly around the year 2030, will require intricate systems for recycling of fluids and waste.

In science fiction, starships are commonplace, whether of alien or human construction. The most sophisticated iteration of the *Star Trek* concept – the exploration of an intelligence-populated universe by a technologically advanced and idealistic humanity – was achieved in the 1990s *Star Trek Voyager* television series. The starship crew are seeking to return to Earth from a distant quadrant of the galaxy, through a space littered with minefields diplomatic, military and epistemological. There are four relevant observations here: (i) although inclusive, the culture of the vessel is American as would be expected from its origins, which as well as extraversion and individualism implies technological specialisation (ii) the starship *Voyager* of the title possesses technologies that not only enable it to travel at multiples of light speed and to create instantly any (relatively small) material item,¹⁷ but allow it to cruise indefinitely – or sustainably – throughout the cosmos, (iii) its on-board artificial intelligence (AI) is not only immortal,¹⁸ but develops as a character and is in many ways more human than those he supports, and (iv) this advanced ship and its mission are a product of a government federation (albeit of a military nature), rather than a means of exploration provided through capitalist enterprise.¹⁹

It is intriguing that such a successful series, made by the most triumphant of entrepreneurial societies, views our exploration of deep space in this way, the same way that our relationship with space began in both the former Soviet Union (USSR) and the US. The motivation, resources, discipline and conscious focus required to conceive, construct and maintain such a complex set of technologies may be beyond capitalism, as it is now for extra-terrestrial

¹⁶ Personal email of 30 August 2015.

¹⁷ Such as a slice of New York cheesecake.

¹⁸ His immortality results from his photonic, rather than carbonic, essence.

¹⁹ The name *Enterprise* – the starship of the original 1960s *Star Trek* series – is the only instance of its occurrence throughout the entire franchise. *Voyager* echoes the names of the two ex-solar spacecraft of the 1970s that carry human images and symbols into deep space.

missions²⁰ – just as it may be beyond capitalism to construct and maintain a renewed and sustainable spaceship Earth.

Anthropocene

The blue marble ‘spaceship’ tends to be static image. Yet the Earth comprises more dynamic processes and systems. The notion of an ‘Anthropocene’ geological epoch is attributed to the Nobel atmosphere chemist Paul Crutzen and the biologist Eugene Stoermer, who reflected on the inadequacy of the post-glacial term ‘Holocene’ in signifying the increasing impact of humanity on the planet. Both thought of the term ‘Anthropocene’ independently and published a joint paper with that title in 2000. In that brief essay they acknowledge the work of Lyall and others in establishing the very concept of geological epochs, but saw a need for a better name for the current era, which they propose began at the time of the Industrial Revolution:

It seems to us more than appropriate to emphasise the central role of mankind in geology and ecology by proposing to use the term “anthropocene” for the current geological epoch. The impacts of current human activities will continue over long periods...because of the anthropogenic emissions of CO₂, climate may depart significantly from natural behaviour over the next 50,000 years (Crutzen & Stoermer 2000, p. 17).

The newsletter in which the article was first published also contains several articles on ‘Earth systems’²¹ as it was around this time that ecological concerns were developing into larger and more dynamic concepts. ‘Earth systems’, which encompass the dynamics of the entire planet, as well as its energy and matter relationships with astronomical phenomena, was pioneered by the early computer modelling of Meadows et al (1972).

The philosopher Clive Hamilton has recently become quite heated on the difference between the static, restricted notion of ‘ecology’ and the dynamic, vast notion of ‘Earth systems’ approaches. His blog is provocatively titled *ecologists-butt-out-you-are-not-entitled-to-redefine-the-anthropocene*:

changes in landscapes, forest clearing, extinction of megafauna, “ecosystem engineering” and so on...[are] entirely irrelevant to the Anthropocene, unless it can be demonstrated that they changed the functioning of the whole Earth system in a detectable way. And they have not been able to do so.

...the difference between ecological thinking versus Earth system thinking lies in divergent understandings of the object to which their thinking is applied. Ecological thinking focuses on ecosystems delimited by their spatial boundaries...this traditional (and in the right context useful) idea has been transcended by Earth system science with a deeper conception of the Earth as a total entity, stretching from the core of the planet to the moon and in an unceasing state of flux driven by natural cycles great and small, a flux in which humans in the Anthropocene have recently become the dominant process (Hamilton 2014, paras 7 and 12).

²⁰ Elon Musk’s private *Space-X* project is acknowledged, but it has yet to put a person into space, which was achieved by the USSR in 1961, more than half a century ago. *Space-X* also depends on NASA contracts that support its operations.

²¹ Such as *Earth System Models of Intermediate Complexity* (Clausen et al, 2000, pp. 4-6) and *Full-Form Earth System Models: Coupled Carbon-Climate Interaction Experiment (the “Flying Leap”)*, Fung et al 2000, pp. 7-8), for example.

Crutzen and Stoermer's original landmark paper does not emphasise these conceptual differences. Nevertheless, Hamilton has a point: 'Earth systems' appear to encompass and vastly extend the notion of 'ecology'. As such, the approach offers hope for a better understanding of sustainability.

Brundtland

More immediate than systems dynamics and conceptions of the Earth, human desires for equity over both time and place are politically serious. The *UN World Commission on the Environment and Development* was set up in 1983 to address wide concerns about the impact of development on the environment. The resulting landmark 1987 Brundtland report, *Our Common Future*, is about 'sustainable development' rather than the more general 'sustainability', but the two topics overlap. Named for the woman former Labour prime minister of Norway who chaired the enquiry, this report famously defined 'sustainable development' as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987, p. 15). This definition is often popularly confused with 'sustainability', whereas it is equally concerned with the politics of development, in particular Third World development and the alleviation of poverty. The issue of how to facilitate economic growth to reduce poverty without environmental damage remains important, but was regarded as a major conundrum during the era.

The same part of the report, however, goes on to link technology, economic growth, equity and political will to the environmental limits on human impact:

The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organisation on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organisation can be both managed and improved to make way for a new era of economic growth...A world in which poverty is endemic will always be prone to ecological and other catastrophes...Yet in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs...Painful choices have to be made. Thus, in the final analysis, sustainable development must rest on political will (Ibid, pp. 15-16)

In his book, *Principles of Sustainability*, Simon Dresner observes that Brundtland's famous definition of sustainable development is both simple and vague, qualities that are both its strength and weakness (Dresner 2008, p. 34). Adams' paper for the IUCN however, is rather more affirmative:

it cleverly captured two fundamental issues, the problem of the environmental degradation that so commonly accompanies economic growth, and yet the need for such growth to alleviate poverty (Adams 2006, p. 2).

According to Seabrook (2002), however, the term 'sustainable development' is an oxymoron.²²

²² Seabrook's observation is consistent with Michael Redclift's (2002 [1987], p. 7) argument that the term sustainable development is "founded on contradiction". Others, notably Herman Daly, have been attributed with similar observations (Redclift 2006, p. 66).

Yet it was believed that the solution to the great clash between ecology and economy had been discovered in the 1980s: this was the idea of "sustainable development", triumphantly enshrined in the Rio declaration. Intra-generational equity would be balanced with inter-generational justice to ensure that we do not take more from the Earth than we give back to it. The excitement generated by this formula concealed the possibility that it might be a contradiction in terms: when unlimited desire is unleashed in a world of limited resources, something has to yield. The "fruits" of industrialism turn out to be strange hybrids - perhaps, ultimately, inedible.

Lélé (1991, p. 607) says the term is too fuzzy and needs to be made more precise. John Dryzek believes that the term has meaning, but that Brundtland more asserted "with great force" rather than argued that the environment and social justice did not have to confront normal material growth, and since then the term 'sustainable development' has become increasingly resigned to conventional concepts of economic growth (Dryzek 2014, p. 13).

Ultimately, Brundtland is a political document that necessarily reflects the undercurrents of the time. It manages to appear both balanced and progressive and it remains an icon in sustainability research, although nearly three decades later it still attracts differing interpretations. According to one respondent to a recent debate on the meaning of sustainability in Australia, the essential aim of the Brundtland report was to stabilise global population:

It was believed that the only politically acceptable way to stabilise population was to elevate the living standards of the then four billion poorest people on Earth, where population was expanding dramatically, to the level of the then one billion people living in the developed world, where population was stable...it was obvious that living standards could not rise unless economic growth, especially in poor countries, accelerated and was sustained for a number of years...So the plan became for "policy makers" to somehow direct most of this five per cent annual global economic growth to the developing world, for decades (Lewis 2015).

However, the report's own statement of its goals is much wider. Brundtland looked at eight key issues, of which population was a part, but a relatively small one. Energy, industry, food security, human settlement and international economic relations were also examples of areas included for analysis (Brundtland 1987, p. 243).

Adams, however, points out that there is a measurement issue, because "there is no agreed way of defining the extent to which sustainability is being achieved in any policy programme" (Adams 2006, p. 4).

Brundtland's compatriots, Asheim & Kjell, look at intergenerational sustainability using mathematical formulations that importantly attempt to operationalise the concept:

If a notion of sustainability is to be of practical importance in the real management of natural and environmental resources, it is essential that the notion is **operational**. The notion becomes operational if the following question can be answered: What kind of rules must our generation follow in order to manage the resource base in such a way that it constitutes a first part of a sustainable development? The problem of finding such rules can only — if at all — be resolved through an analysis of the long-term global production possibilities (Asheim & Kjell 1993, p. 3).

They also introduce the notion of risk: "The crucial question is whether the risk of decreasing future quality of life is acceptable" (Ibid).

As far as the discourse about sustainability is concerned, the Brundtland report indicates an awareness of contemporary connotations of key words, especially 'environment' and 'development'.

The environment does not exist as a sphere separate from human actions, ambitions, and needs, and attempts to defend it in isolation from human concerns have given the very word "environment" a connotation of naivety in some political circles. The word "development" has also been narrowed by some into a very limited focus, along the lines of "what poor nations should do to become richer", and thus again is automatically dismissed by many in the international arena as being a concern of specialists" (Brundtland 1987, p. 7).

In the thirty years since the report, there have been changes in terminologies and different emphases on different words, possibly in attempts to escape the sort of connotations Brundtland identifies. For example, an emphasis on 'the greenhouse effect' became 'global warming' then more recently, 'climate change', which underlines its negative effects. The 'environment', something separate from humanity, has tended to be replaced by the 'biosphere', which emphasises its global relationship to life, or 'ecosystem', which underlines its characteristic as an inter-related system.

From a critical neo-Marxist perspective, Arturo Escobar argues that the discourse of 'sustainable development' only reshuffles the elements of neo-liberal development theories: basic needs, population, resources, technology, etc. (Escobar, 1995, p. 195). And overarching the development discourse is that modernity can only be achieved through the development expert – "the wise white man from the West" (Röwert 2011, p. 2). Whether sustainable or not, it is argued that the very concept of development reinforces racial and cultural stereotyping. As Hilary Hove (2004, p. 49) puts it, "sustainable development simply embodies a new form of the old discourse; it fails to emerge from its ethnocentric vices". She argues that due to "its emphasis on sustainable growth" the policy does not account for how the West "contributes to the inferiority and subordination of poorer parts of the world". Escobar also points out that the bond with sustainability essentially just means that the 'wise white man from the West' is as likely to be an environmental scientist as an economist:

The Western scientist continues to speak for the Earth. God forbid that the Peruvian peasant, an African nomad, or a rubber tapper of the Amazon would have something to say in this regard (Escobar 1995, p. 194).

Critics from the political left emphasise that the sustainable development concept does not address the issue of unsustainable consumption of the West, which for sustainability must be a central concern. Rather, it both assumes and reinforces a globalised homogeneity, in which social diversity is "disciplined" according to the dictates of the interests of capital. Fernando (2003, p. 6), for example, asserts that achieving the goals of sustainable development – addressing both socio-economic inequality and environmental degradation – means that it "must be liberated from the ideology and institutional parameters of capitalism". But while much of this sort of criticism is compelling, it tends to lead towards unlikely social and political outcomes. As there appears to be little coherence in leftist political movements towards a sustainable development that is separate from global capitalism, it is doubtful that there will

be major revolutionary political and economic change in that direction, despite some localised efforts in South America. This study therefore attempts a more pragmatic approach in which it is assumed that a form (or forms) of capitalism will continue, but also that it may be channelled more responsibly.

Earth summits

After Brundtland, the UN 1992 Rio *Earth Summit* encouraged ways of merging development with environmental protection, producing the 300-page *Agenda 21*, and the *Rio Declaration on Environment and Development*, as well as opening conventions for signature on biodiversity, climate change and desertification. The title 'Agenda 21' refers to priorities for the twenty-first century. It contains four sections concerning poverty reduction, environmental conservation, empowering marginalised groups and means of implementation respectively. Three follow-up Earth Summits were held in 1997 (*Rio+5*), 2002 (*+10*) and 2012 (*+20*) to revisit the commitments made under Agenda 21.

Lack of progress on implementing the principles of the Earth summits is often ascribed to North-South attitudes to economic development and environmental impact. Agenda 21's introduction, however, wastes no time in launching into an enthusiasm for trade liberalisation, a policy area still scarred from battles between the environment and the (neoliberal) economy:

An open, equitable, secure, non-discriminatory and predictable multilateral trading system that is consistent with the goals of sustainable development and leads to the optimal distribution of global production in accordance with comparative advantage is of benefit to all trading partners (UNCED 1992, s.2.5).

This may help explain slow progress. The WTO and regional trade agreements that have evolved since the late 1980s have tended to reduce rather than extend environmental protections in the name of economic efficiency.

Trade

One example of these battles is the World Trade Organisation (WTO) tuna-dolphin cases of 1990 and 2008. The outcome of these disputes was that US import restrictions on tuna caught with fishing methods that incidentally killed dolphin were not upheld (Oxley 2001, p. 5, Miles 2012). In effect, the WTO asserted that its purpose was purely the pursuit of trade liberalisation. Environmental matters were separate, for other forums. Since the stalling of progress with trade liberalisation at the Doha round, however, emphasis on multi-lateral instruments has slowed in favour of increasing numbers of bi-lateral and more limited multi-lateral free trade agreements.

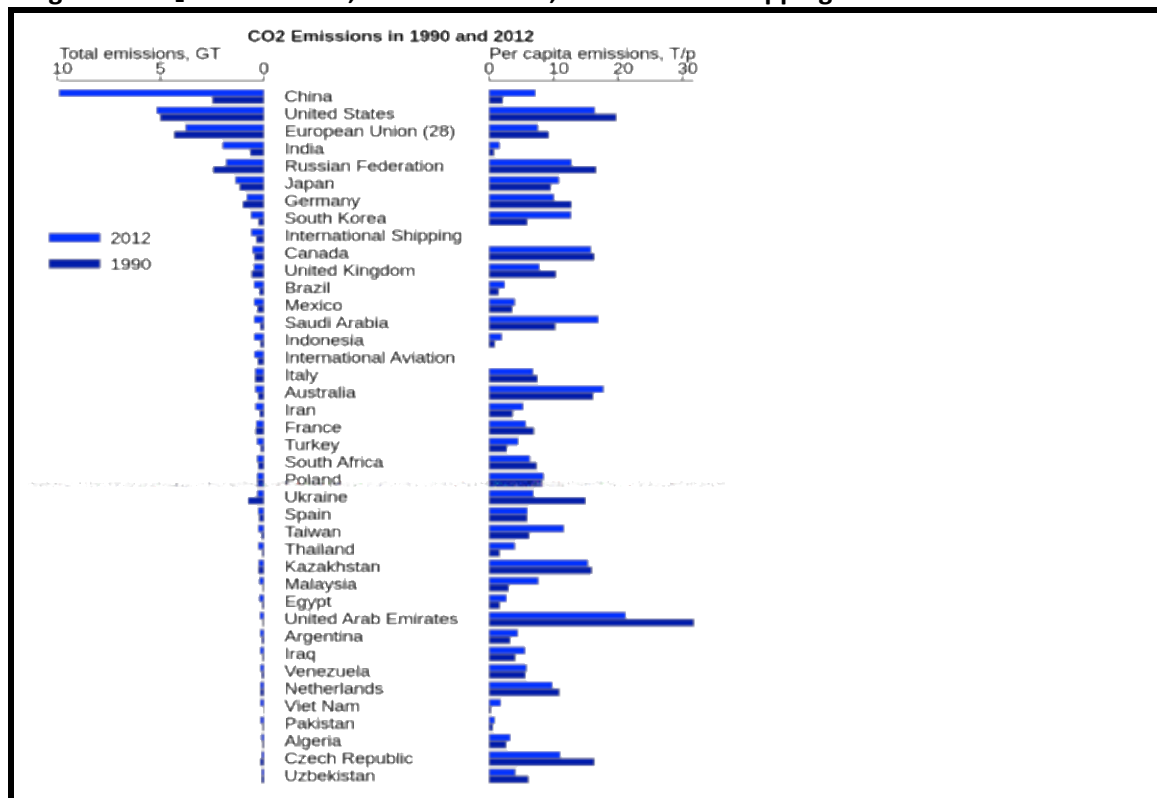
But trade can be antipathetic to sustainability more generally, and further, trade volumes are affected by technology. The classic Smith-Ricardo theory of comparative advantage shows that it is mutually beneficial for countries to trade goods that they can produce relatively efficiently compared with other goods in the same country, with countries that have different relativities.

But transportation costs can reduce or eliminate the economic benefits from trade, including comparative advantage. Paul Krugman, who once asserted that "almost nobody understands such abstruse concepts as comparative advantage" (Krugman 1995, p. 329), later used the same example as Ricardo to show that if transport and related costs exceed the production advantage, there is no advantage in trade (Krugman 2010, para. 4).

Krugman speculates that changes in the cost of trade relative to production costs affect trade volumes. If trade costs fall, as they did in the late nineteenth century due to steam-powered shipping and the inter-ocean canals, trade increases. Conversely, if trade (especially transport) costs rise or if production costs fall faster than transport costs (as with the electrification of factories between the wars), then trade decreases. Containerisation, larger ships, jumbo aircraft and progressive tariff removal in the late twentieth century meant that trade increased because transport was effectively cheaper (Ibid, paras 6-8). Thus the relationship between dominant transport and production technologies affects trade volumes.

The significance of these observations for sustainability is that more trade implies more emissions associated with the transport of goods and services. Therefore, reduced trade is beneficial to sustainability. Krugman's insight is especially significant in the present era of complex international supply chains that draw heavily on long distance transport to assemble and bring the final product to market. The impact of trade is substantial. If it were a country, international shipping would be the ninth largest emitter of carbon dioxide. Aviation would be sixteenth, as shown in figure 4 below.

Figure 4. CO₂ emissions EU, other countries, international shipping and aviation.

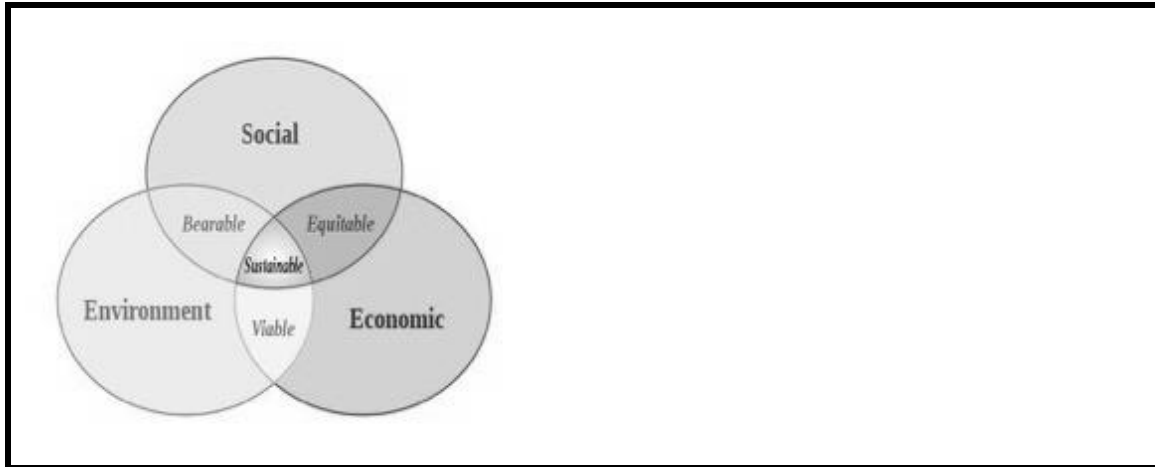


Source: EU emissions database: Emissions database for global atmospheric research (EDGAR) 2014

Components

Trade can be detrimental to sustainability due to its emissions, but sustainability is often conceived of as other than just environmental impact. The IUCN's Adams (2006, p. 2) has one of three diagrams describing the concept of sustainability as the centre of a triple intersection of economic, social and environmental concerns. A related image is at figure 5 below, which suggests that sustainability is at the centre of the socially and environmentally bearable, the socially and economically equitable and the environmentally and economically viable.

Figure 5. Sustainability: bearable, equitable and viable.



Source: Choi 2015, p.14789

These three areas are routinely used in business to describe what is termed the ‘triple bottom line’, whereby an organisation aims to be economically and socially, as well as environmentally, sustainable. While arguably it is the environment that is the most important since the other two both depend on it, these differing perspectives are based on different values making an interdisciplinary approach to sustainability more challenging (Ostrom 2009, p. 419; Gale et al 2015, p. 253).

Environmental sustainability can itself be split into three parts, all of which relate to natural capital.²³ In 1990 the pioneer ecological economist, Herman Daly (1990, pp. 1-4) proposed that (i) for renewable resources, the rate of harvest should not exceed the rate of regeneration (sustainable yield); (ii) for non-renewable resources, depletion should not exceed the creation of renewable substitutes (sustainable depletion); and (iii) for pollution, the rate of waste generation should not exceed the capacity of the environment to assimilate it (sustainable assimilation). Thus, environmental sustainability is the rate of renewable yield, non-renewable depletion and waste assimilation that can be continued indefinitely. If they cannot be continued indefinitely then they are not sustainable.

While the issue of renewable substitutes for non-renewable resources is potentially the most challenging – including substitutes for rare earths used in electrical storage as well as substitutes for fossil fuels – there is the issue of quality as against quantity in all three of Daly’s dimensions. For example, a sustainable harvest might still occur in volume, but the quality of the harvest may decline. This is arguably true of meat production in some countries where animals destined for slaughter are fed chemicals to speed production volume, but the quality suffers as a result. Where fewer crops replace more diverse plantings, production may be sustainable, but variation, choice and biodiversity suffer. Also in many cases substitutes are not as suitable as the original resource – plastics instead of metal for example in many applications. Further, the determination of when waste assimilation is complete and successful is problematic.

Governance

Before implementation, furthering such aims implies goal-setting and regulation. There has been at best mixed success with global regulation in favour of sustainability. While the Rio 1992 Earth Summit proclaimed lofty principles, many of them still await means of

²³ Although Daly uses the term in the article cited, it must be noted that the term ‘natural capital’ remains controversial due to its perceived diminution of nature as simply a resource for humanity.

implementation and enforcement. More recently there has been the 2004 *Rotterdam Convention* on informed consent for trade in toxic substances, and the *Stockholm Convention* of 2004 limiting persistent organic pollutants. In 2012, the UN Secretary-General's High level panel on global sustainability (UNHPGS) made several recommendations on governance, including ensuring a stronger interface between policy-making and science (R.44) and the creation of the SDGs at R.48. But many aspects such as the protection of biodiversity, measures to prevent desertification and to control climate change have so far made "regrettably few" advances (Pope Francis 2015, s. 168-169). What is needed, he says are ways to effect systems of governance for the whole range of the "global commons" (Ibid, s.174).

John Dryzek in discussing institutions for Anthropocene governance remarks that what counts is convergence of expectations rather than rules and regulation:

Institutions are in large measure discursive constructions: they work because of a convergence of expectations and understandings, not just formal rules. So, for example, market liberal globalisation is so powerful in large measure because it permeates the understandings of actors in the political economy. Policy deviations from its orthodoxy are punished not just by impersonal market forces, but because people in key positions in financial and economic institutions believe those deviations will have negative economic consequences, and so may disinvest in the deviant state (Dryzek 2014, p. 12).

Iconic imagery is also important in the force of ideas. The idea of an 'ozone hole' in the negotiations leading up to the *Montreal Protocol* contributed to its adoption and apparent success (Ibid pp. 13-14). However, the metrics of sustainability regulation often present greater difficulty. Adams (2006, p. 4) says that often at the practical program level sustainability is less measured than 'genuflected', less achievable than aspirational, "a victim of the desire to set targets and measure progress".

More positively, however, the Sustainable Development Goals (SDGs) for 2016 – 2030 combine indicators of progress with some of the major elements of sustainability. For example, target 6.3, as well as minimising water pollution, involves "halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally" by 2030. The proportion of untreated wastewater will therefore be measured and progress monitored. This promises to be more than an empty gesture and should inform program measurement at the national level.

Paradox and pessimism

Simon Dresner's influential treatise on sustainability, re-written at the time of the GFC and the subsequent global recession,²⁴ makes the case for "an attempt to make our civilisation more sustainable than it presently is" despite the impossibility of drawing up "a detailed blueprint of a sustainable society or even a route to get to it". Dresner's historical analysis draws heavily on discussions of economic growth and the displacement of traditional religion by triumphant Western consumerism. He compares the failure of communism, due to the impossibility of central planning of a complex modern economy (Hayek) and due to transformative communication technologies destroying tradition and stability (Giddens) with socialism, which although "discredited" entails valuable concerns with equality and fairness. These concerns he says, now need to be associated with concerns for "nature, risk, growth and technology" (Dresner 2008, p. 179).

²⁴ Second edition. The original edition was written in 2002.

Dresner's take on neoliberal economics with its emphasis on growth is that it is a reflection of Smithian rationalist influence over the past 200 years, which has been predominant over the alternative 'respect for nature' Enlightenment tradition of Rousseau. He points out that the neoliberal "seductive message" that markets alone will make government planning unnecessary (Ibid, p. 175) and the problem of "accumulation without end" assumed by Fukuyama (1991) and criticised by Giddens (1994), is clearly absurd (Dresner 2008, p. 160, Higgs 2015).

While he uses the terms 'liberal democratic capitalism' and 'liberal democracy' interchangeably, Dresner (pp. 144-153) believes that the market is central to them both. The essence of his view is at page 144: "we can try to be sustainable or we can pursue the free market, but we can't do both." This is rather different in Gore (2013, p. 33), who prefers a system of "sustainable capitalism", whereby the market is still paramount, but it must factor in environmental impact (Ibid, p. 35).

The notion of *paradox* is sprinkled throughout Dresner's book. One paradox of sustainability is that its pursuit depends on a global community linked through the Internet and other technologies, yet these technologies at the same time tend to prevent needed prediction due to the rapid social change they engender (Ibid, p. 179). Post-modernists believe in a diversity of moral values and are therefore unable to argue against fundamentalist values that would deny moral diversity, including those that might be needed to save the planet (Ibid, p. 170). And the paradox of utilitarianism is that people are expected to accept less for the sake of those who are already more fortunate (Ibid, p. 131). Elsewhere in this dissertation is found the Jevons paradox (1.6) whereby more fuel efficient machines result in more fuel used. There is also the paradox of biodiversity -- that the more species we render extinct, the more 'new' species we discover.

While these apparent contradictions are important, Dresner also points out an irony – that sustainability arose on the political agenda during the 1980s just as the ideologies that might support it were being abandoned for neoliberalism. In a similar vein, Garnaut (2014) points out that it took half a century for neoliberal economics to shrug off the taint of the Great Depression and achieve the sort of global dominance it enjoyed until the GFC in 2008. Wesley Widmaier (2015, paras 7-12) argues that since the 1987 crash all neoliberal economics has given us is a series of "bubbles and bailouts" based on demand created by asset price increases rather than the wage increases of the Keynesian era. In this current economic period where growth is listless²⁵ and volatility rules, sustainability struggles for the attention it demands.

Dresner identifies a contemporary mood of pessimism about the future, which is in contrast to the attitude of the Victorians. The very slogan 'sustainable development' is but an attempt to sound optimistic about a doubtful future, he says (Dresner 2008, p. 19). This fits with Arthur Clarke's earlier observation that "this is the first age that has paid much attention to the future, which is ironic since we may not have one". And if the results of a recent four-nation²⁶ survey are indicative beyond the Anglosphere, pessimism is the mood of our era. More than half the 2000 people surveyed rate the risk of our civilisation ending within 100 years as at

²⁵ For example, "longer-term potential growth rates remain subdued across the globe compared with past decades, especially in advanced economies" (IMF 2017b, p. xii).

²⁶ Australia, Canada, the UK and the US.

least 50 per cent; almost a quarter believe there is the same risk of actual human extinction within the same timeframe (Randle & Eckersley 2015).

Principles

Dresner also collaborated with Ekins et al (2008 pp. 68-9), who outline four principles that affect what method is best for evaluating sustainable development policies, both at point of contemplation and after implementation. The principles are sustainability, precautionary, appropriateness and justice.

The environmental *sustainability* principle concerns the need to maintain critical environmental functions for future generations. These functions include climate stability, maintaining the ozone layer and preserving biodiversity, ensuring environmental quality and avoiding pollution. Clearly we are not doing well against this one; at least the last three are worsening.

The *precautionary* principle is about avoiding irreversibility. The loss of particular environmental functions may cost dearly to remedy, or may not be recoverable at all once lost. Therefore because of risk uncertainty, actions that could result in very large costs should not be embarked on, even if there is little chance of their occurrence and high chance of benefits. This principle tends to dampen the zeal of geo-engineering enthusiasts. Exactly where the principle is invoked, however, is a political matter to be decided – or ignored – in each case.

The *appropriateness* principle relates to situations where assessing financial trade-offs is morally inappropriate. ‘Willingness to pay’ needs to be consistent with ‘ability to pay’ – what poor people are willing to pay for environmental benefits is unlikely to be what they think something is actually worth, because they cannot afford to pay much at all. Therefore ‘willingness to pay’ approaches to environmental resource allocation are often inappropriate because the priorities they indicate will automatically favour the better off.

The principle of *justice* also applies. While the point above demonstrates marginal valuations may be in conflict with justice, the example of social costs and benefits in the IPCC’s Second Assessment Report was of a different order to mere moral inconsistency. Ekins et al (2008, p.69) suggest that the report was “met with outrage” because lives in rich countries were valued 15 times greater than lives in poor countries. Further, “no distinction was made between those responsible for anthropogenic climate change and those likely to suffer its consequences”.

However, while these principles apply to sustainable development policies, those policies are applied in a world driven by considerations of the ‘dismal science’: economics.

Ecological economics

As Paul Erlich (2009) has observed, the words ‘economy’ and ‘ecology’ are from the same root. While in English one derives from sixteenth century usage, the other was a German invention of the nineteenth century (Kurtz 2006). Ecology was about management of the household’s physical resources while economy was about management of the household’s financial resources (Ellerbrook 1998). The origin of the two terms is now apposite as we have reached the limiting household size – the extent of the planet Earth.

Eriksson & Anderson (2010, p. 2) in outlining the elements of ecological economics, articulate the ‘trilemma’ of global social justice, prosperity and ecological sustainability. While the

difficulty of resolving any two is high, resolving all three is much harder. They point to several recent reports (World Bank, ILO) that attempt to address two of the three, with little or no mention of the third. Ecological economics arose from the need to address all three of these meta-issues that we now face on this planet.

Building a bridge between ecological and the still dominant neoclassical²⁷ economics, however, is difficult. Ecological and neoclassical economists do not necessarily share the same concepts, if one large study is typical. In an international workshop on economic sustainability held in Berlin in 2003, participants became involved in a heated discussion about whether economic growth is desirable for sustainable development. Ecological economists were concerned about the physical aspects of economic growth – material resources, emissions and waste. Neoclassical economists rather had a monetary concept of growth measurable by GDP and which would not necessarily increase environmental harm. While both groups ultimately agreed that decoupling economic activity from harmful environmental effects is a desirable goal, opinions differed on how to achieve it (Illge & Schwarze 2006, p. 3).

Nevertheless, the 196 questionnaires returned by participants showed there is some common ground between disciplines. For example, there was agreement that sustainability means preserving development opportunities for future generations. It was also agreed that economic growth is not the only way to solve the conflict between efficiency and equitable distribution, that sustainability is an important field of economic research and that sustainability research must rise above the boundaries between disciplines.

Ecological economists, however, were alone in believing that an integrated understanding of economic, ecological and social welfare is essential to sustainability. Only they believe that human-made capital rarely substitutes for natural capital, that the economy depends on nature, and that the value of an intact environment cannot be measured in money. They alone believe that changing societal values is important to achieving sustainability rather than through a self-interested view of human nature. Sustainability economics must deal with the question of how to make decisions in an intergenerational context. Economic science should not be value-free.

Neoclassical environmental economists, on the other hand, do not believe that inter-generational justice presupposes intra-generational justice. They are alone in believing that sustainability does not require restrictions on material consumption, that it may be achievable within the present economic system by setting the 'right' prices. They uniquely believe that international specialisation leads to more long-lasting wealth worldwide, and that economic science should be objective.

Another schism is the concept of science: economics has to be objective and 'value-free' according to the neo-classicists, whereas ecological economists tend to have a post-modern view of science as necessarily value-laden (Ibid, p. 20).

The former World Bank chief economist and Nobel laureate, Joseph Stiglitz, manages to steer a course between the two camps in terms of practical policy. While at present there are considerable subsidies involved in the production and consumption of polluting substances such as fossil fuels in many countries, Stiglitz says that it is "better to tax bad things than good things, because that way you get a double benefit" – revenue from the tax as well as less harmful activity. Hence the most critical thing for sustainability is to put a price on pollutants such as

²⁷ 'Neoclassical' economics is a school of economics that assumes rational actors within markets that balance supply and demand. Much of its approach is used in the political ideology of neoliberalism.

carbon – a carbon tax. Removal of subsidies on carbon production would also improve government revenue while at the same time reduce environmental harm and increase efficiency (Stiglitz 2014).

Others, notably Costanza et al (2014), have grasped the nettle of putting a monetary value on nature. While they emphasise that doing so is not privatising or commodifying ecosystem services, and that the value estimates are more *use (or non-use)* rather than *exchange* values (Ibid, pp. 153-154), it is obvious from their paper that there has been marked criticism of the concept. Original estimates in an earlier article in *Nature* (Costanza et al 1997) showed that the value of ecosystem services exceeded global GDP at the time. On the other hand, Jesse Ausubel (2014) argues that “we must make nature worthless” so that it can be owned by those wishing to conserve it and rendered unnecessary in the pursuit of an economy based on common, rather than rare, substances such as silicon. Humanity would thrive in dense communities that did not rely on chlorophyll, leaving larger areas to return to nature, as has happened already in the US North East for example.

Decoupling

Decoupling refers to the possibility of achieving economic growth without environmental harm. The concept is similar to the idea of ‘dematerialisation’, by which economic growth is increasingly based on non-material outputs such as services, entertainment and software forms rather than on physical goods.

There is a distinction between absolute and relative decoupling. In relative decoupling the growth rate of the environmental parameter is less than the economic parameter, but is still positive. Whereas absolute decoupling involves a zero or negative growth rate of the environmental parameter as the economy grows (UNEP 2010 p. 18).

At least in respect of carbon pollution of the atmosphere, decoupling has not yet been achieved:

Globally, economic and population growth continue to be the most important drivers of increases in CO₂ emissions from fossil fuel combustion... Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity... Increased use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonisation of the world’s energy supply (IPCC 2014d, p. 9)

Dietz & O’Neill (2013, p. 117) propose that our “obsession with GDP” can promote economic growth that is harmful. They say that our ecological overshoot is at least partly due to our narrow group of economic indicators, especially GDP. Ward et al (2016) agree:

We have shown that there is little evidence that GDP growth can be decoupled in the long-term (i.e. it is not sustainable) ...it is ultimately necessary for nations and the world to transition to a steady or declining GDP scenario.

Capitalism

Dennis Meadows of the Massachusetts Institute of Technology (MIT), one of the original authors of *The Limits to Growth* (1972), now believes that sustainability cannot be achieved within the present financial system:

A fish will never create fire while immersed in water.²⁸ We will never create sustainability while immersed in the present financial system. There is no tax, or interest rate, or disclosure requirement that can overcome the many ways the current money system blocks sustainability...I now understand, as proven clearly in this text, that the prevailing financial system is incompatible with sustainability in five ways:

- it causes boom and bust cycles in the economy
- it produces short-term thinking
- it requires unending growth
- it concentrates wealth
- it destroys social capital (Meadows in Lietaer et al 2012, p. 6).

Seabrook (2002) is in accord. For him, 'sustainability' has been distorted to mean the economic rather than the environmental kind:

'Sustainable' now means what the market, not the Earth, can bear; what originally meant adjusting the industrial technosphere so that it should not destroy the planet has now come to indicate the regenerative power of the economy, no matter how it may degrade the "environment". Sustainable is what the rich and powerful can get away with.

Much earlier, Karl Polanyi (2001 [1944], p. 136) had written of the natural world that the "market economy, if left to evolve according to its own laws would create great and permanent evils". These would result because "food supplies...the climate...the denudation of forests...erosions, and dustbowls" do not respond to the supply-and-demand mechanism of the market (Ibid, p. 193).

And yet, reflecting on Meadows' five incompatibilities, none of them is necessarily irreconcilable with a sustainable world. Certainly they are all discordant social issues, but they do not directly conflict with sustainability. Boom and bust economic cycles are undesirable socially and politically, but they do not in themselves necessarily have adverse environmental effects. Short-term thought is less revered than long-term thinking, but grand masterplans are no guarantee of success, as Napoleon and Hitler exemplify. Whereas the art of 'muddling through' has serious underpinning in public policy (Lindblom 1959 and 1979; Forester 1984). A series of short-term incremental policy steps are often the only practical way to proceed.

Unending growth, or as Higgs (2015) puts it "endless growth on a finite planet", seems the most cogent of these incompatibilities. Yet, ultimately the growth involved is – as our Berlin neoclassical economists assert – ephemeral. It is economic. It is money. It is a concept of exchange value. It is a number on a screen, not necessarily the consumption of materials or energy. A Rembrandt has an exchange value millions of times its physical content. A software program may be extremely valuable but is immaterial. And increasingly economies depend on growth in services rather than goods. At least in the developed world, most people have more than enough 'stuff' and economic growth is decoupling from physical possessions. It seems possible that not only can growth be de-materialised, but the innovation that it enables can lead to sustainability rather than to degradation. According to Nicholas Stern in *The Economics of Climate Change* (2006), for example: "growth is part of the solution to climate change. Most growth is the result of innovation – the development of new products, new techniques and new ways of doing things that are an improvement on what went before. The next wave looks like it will be dominated by digital technology, robotics, biotech, lighter materials and

²⁸ This is an odd metaphor: fish do not create fire, whether immersed in water or not.

renewable energy...To say that we have to stop growing – that we have to go backwards – I think is factually wrong, and also politically unlikely to be successful...We absolutely can have growth and protection of the climate at the same time, and in doing so we will construct a much better form of economic activity and growth in terms of clean air, less-congested cities and so on”.

Concentration of wealth is not only inequitable and socially undesirable; it can also have indirect adverse environmental effects – through both excessive consumption and the insulation of the wealthy from the consequences of unsustainable practices. Yet this is not necessarily disastrous. Governments can still make laws that assuage inequities while keeping reasonable incentives. Information is increasingly available to anyone. New platforms can democratise the media and political activism is a counterweight to the power of wealth.

Lastly, the destruction of ‘social capital’, or the promotion of selfish and non-collaborative behaviours, is documented. Certainly it would reduce societal cohesion. And it would weigh against environmental well-being, which would be ignored in pursuit of individual gain. But to say that the financial system destroys social capital is absurd. The central study on the issue ascribed the decline of US social capital to television, not the financial system (Putnam 1995). Also, while the financial system has been around for hundreds of years, social capital has apparently yet to be destroyed. Lastly, social capital can be constructed in pursuit of financial ends. Finance is not intrinsically evil – although money may well be at its root.

As to Seabrook’s view that the economically powerful distort ‘the environment’ to mean ‘the economy’, there are means to counter such forces – the glare of social media on environmental issues for one. Polanyi’s warning of unrestrained markets implies that markets must be restrained for the good of both natural and human sustainability.

Still others have more aggressive views, but along similar lines to Meadows. Joel Kovel, ecosocialist academic and former US Green party presidential candidate for example, believes that “capital is the efficient cause of the [ecological] crisis”. He is concerned about “the general acceptance of capitalism as having a kind of divine right to organise society, and the coordinated refusal to face up to its essential ecodestructivity” (Kovel 2007, p. 164). This is an observation that resonates, especially since Fukuyama’s ‘end of history’ neoliberal capitalist triumphalism at the end of the Cold War, although traditional socialist economic models have been less than exemplary in this regard as well.

Two visions

The US biologist John Vucetich observes ruefully that in the modern world we can have human prosperity in the absence of once-abundant life. “There are so few black-footed ferrets on the planet that we’ve already proved we don’t need them,” he says. “You can list hundreds of species we can get along fine without”. Vucetich sees the fight over green modernism as a clash between two visions of sustainability: one that exploits nature as much as we like without infringing on future exploitation, and one that exploits nature as little as necessary to lead a meaningful life. “It’s hard to imagine those two world views would lead to the same place,” he says. “I think they would lead to wildly different worlds” (quoted in Keim 2014, paras. 48-49).

However, human prosperity does not necessarily mean the elimination of other forms of life. The return of some areas to the wild (‘rewilding’) is happening in parts of the US and Europe, for example (Monbiot 2014b). And when such habitats are physically linked and their scale increased, nature becomes more resilient, more sustainable.

Further, Dame Ellen MacArthur (2015), who has real-life experience of sustainability at sea, believes that it is not economic growth or capitalism that is the problem, rather it is the linear nature of the economy that extracts, uses and degrades in the pursuit of material wealth. She believes that a circular economy like a life system would enable sustainability – one in which people buy transport services, not cars and buy lighting services, not lights. This is a world where we ‘use things’ rather than ‘using them up’ and where organic wastes are recycled as fertiliser. Some of this may have been informed by Hawken, Lovins & Lovins (2015, p. 8) who argue that the abundant natural capital and scarce labour of the industrial revolution is giving way to the converse – scarce natural capital and abundant labour. Nature can no longer be regarded as free to exploit. Hence economic and production systems must be redesigned to be vastly more efficient and to produce no waste at all.

If it can't be reduced, reused, repaired, rebuilt, refurbished, refinished, resold, recycled or composted, then it should be restricted, redesigned, or removed

– Pete Seeger, cited in Svedrup & Ragnarsdóttir 2015, p. 277.

Nightfall

Isaac Asimov's *Nightfall* (1941) imagines a world that orbits several suns, that produces continuous daylight throughout the planet, except for a period of nightfall that occurs but once every thousand years. The people of the planet do not expect this new phenomenon and are driven insane by darkness and the vista of the heavens that opens infinitely above them. The civilisation they build collapses, as fires are widespread in desperate attempts to produce light. Ultimately, a new civilisation emerges from the ashes of the old, until the darkness again returns after a further millennium. The plot tension centres on archaeological discoveries of several previous civilisations separated by layers of ash. Can this evidence be interpreted correctly, or will the next imminent round of darkness overwhelm the discovery of the truth and the means to deal with it? Arguably this scenario is not far from the current predicament of humanity on Earth. We already have strong evidence that our civilisation is unsustainable and we do know largely how to deal with it. The issue is rather how to deal with the political and economic consequences of such actions.

Roadmap

The underlying theme of Al Gore's book *The Future* (2013) is finding a way out of the fossil-fuel climate crisis, which has still wider application for sustainability. In charting a route, Gore outlines six ‘drivers’ of global change, the major forces that offer hope for a sustainable future. In Dryzek's discourse framework (figure 2), this is a sustainability that is both imaginative and reformist.

Gore's sounding the alarm about global warming,²⁹ as well as his efforts to secure the 1997 Kyoto protocols when US Vice-President, entitle him to some regard in matters of sustainability. Not everyone endorses his views, however. From the left, Joel Kovel (2007, p. 166) believes that “history will be kind to Gore”, but says it is wrong to set the logic of change within the dominant (capitalist) system. Nevertheless, Gore's drivers form a plausible roadmap:

The first driver is the integrated global web of corporations, finance and markets that now dominates liberal democracies. The second is the emerging “global mind” – humanity linked through the Internet and other digital communications that enables alternative political

²⁹ As portrayed in the film *An Inconvenient Truth* (2006).

movements, new business forms that dispense with the middleman, and linked sensors, databases and intelligent machines. Gore's third factor is the shift in political and economic power from the global North to the global South.³⁰ His fourth driver is "outgrowth", whereby the global population increase is more in the South, especially Africa. While this population increase puts added burdens on resources, it should also lead to the benefits of urbanisation and to population restraint through the education of girls, the empowerment of women, the availability of contraception and the reduction of death rates.

His fifth driver is genetic and biological research, especially advances in neuroscience. Combined with progress in cloud computing and artificial intelligence, such technologies have yet to impact on public understanding of their potential. In this respect, the World Bank-IMF spring meeting in 2015 included focus on how cloud data can be exploited in ways yet unimagined. As a result of interconnected sensors and other data gathering facilities, the cloud now contains vast and increasing amounts of data that are available for 'mining' – to create new models and ways of approaching intricate problems. Gore's final driver is the technological breakthroughs in renewable energy, materials and resource re-use. He sees (US) euphoria over shale oil and gas as short-lived due to its minimal net energy output, its huge demand for water and its toxic methods. The main obstructions are the corruption of democracies through money from established industries and 'science deniers' who may fight the disruptive technologies of the future.

Consistent with Gore's view of cloud computing and AI, the originators of the term 'anthropocene' believe that sustainability must be based on information technologies:

To develop a world-wide accepted strategy leading to sustainability of ecosystems against human induced stresses will be one of the great future tasks of mankind, requiring intensive research efforts and wise application of the knowledge thus acquired in the noösphere, better known as the knowledge or information society (Crutzen & Stoermer 2000, p. 18).

However, Adams (2006, p. 14) speaks of imagination imprisoned and the importance of political heart:

The existing language of sustainability has become a prison for the imagination. It limits the capacity of partners to respond to the challenge of planetary future (e.g. language of choices, trade-offs). The elements needed for the future are easily stated, although very challenging to work through. They include imagination, vision, passion and emotion. The issue of emotion is probably central to success. Existing approaches to sustainability have depended heavily on natural science (from which the concept came), and economics. 'Dismal science' in all forms remains essential to charting a course to the future, but it is not enough to drive changes needed. The world is not run by technocrats (even economists), but politicians and the citizens they represent or govern. In the past sustainability has engaged the mind, but the future demands an engagement with the hearts as well.

Others, such as the historian Lynn White writing in 1967, see the origins of our sustainability crisis in the overly-successful and destructive combination of Western science, Christianity and technology, whereby not only do we see ourselves as rightly dominant over nature but have the means to assert it. His solution is based on the values of St Francis, who saw all creatures as equal (White 1967, p. 1207), since echoed in Pope Francis' *Laudato si': on care for our*

³⁰ Including Asia, Latin America and Africa.

common home (2015). There is little doubt that the road to sustainability must require a change of values. However, the half century since White has not been encouraging. For example, former Google engineer, Anthony Levandowski's announced mission to develop a "Godhead based on artificial intelligence" to worship and help develop society (Sacacas 2017) is bizarre in its combination of religion and technology; values are diminished in an idolatry of power over nature. Humanity will best focus where there is the most leverage. And in this Gore's drivers offer more practical hope in the shorter term – which may be all that we have.

Conclusion

The factors of sustainability can be considered in terms of both origins and consequences. The IPAT relationship has changed since its conception according to presumptions of the factors of environmental impact, but still provides a framework on which to consider the causal elements of sustainability. Daly's 1990s considerations of the natural capital aspects of sustainability balance that structure on the effects side (figure 6):

Figure 6: Factors of sustainability

Cause		Sustainability	Effect	
Population	→		↗←	↖ Yield
Affluence	→		←	Depletion
Technology	→		←	Assimilation

Much of the debate about sustainability is one between biologists, who more easily see the environmental effects of our species, and those economists who have faith in the market as the ultimate arbiter and who therefore dispute the nature of intervention required. A third group are the visionaries who view sustainability from wider perspectives, whether they are science fiction writers, astronomers or inventors. But while science, economics and the far-sighted might inform sustainability, to achieve sustainability humanity must focus where there is significant leverage. Population policies, even if politically acceptable, take a long time to effect and still longer to show results. Although many favour its redistribution, few politicians are in favour of less affluence. But while our embrace with industrial technology has produced this crisis, our partner changes with bewildering speed, perhaps enough to baffle the conundrum of sustainability itself.

In the end, however, sustainability is a matter of politics that involves perceptions about equality – which is probably why the landmark *Brundtland* report on sustainable development was headed by an accomplished politician. In line with Dryzek (1997), there are several discourses that challenge the dominance of industrialism in different ways and to varying degrees, the task of politics is still to establish a narrative that finds wide support to underpin the actions needed to bring sustainability about – before the long night falls.

The following chapters 3 to 6 discuss in sequence the elements that contribute to sustainability, following the formula of the classic IPAT relationship. Thus *impact*, *population*, *affluence* and *technology* are presented and discussed separately. The final chapter 7 of this part is an assessment of our sustainability trajectory and the options for dealing with it.

We shall continue to have a worsening ecological crisis until we reject the Christian axiom that nature has no reason for existence save to serve man – Lynn White 1967, p. 1207.

Chapter 3. Impact

*Between the idea
And the reality
Between the motion
And the act
Falls the Shadow*

– Eliot, *the Hollow Men*

The context of this part of the dissertation is how to establish the current and future impact of our species, *Homo sapiens*, on the planet on which we live and especially on our own sustainability. In line with the ‘Earth systems’ concept discussed earlier, this chapter argues that we must approach the question from a planetary perspective, rather than any narrower viewpoint. It compares our species to others and examines whether human impact is already unsustainable in relation to particular measures such as biodiversity. It examines significant literature and also analyses the elements of IPAT to highlight human energy practice as a particular concern.

Frontiers no longer exist. There is no other world to which we can escape should that impact be terminal. Yet the wider perspective of astrobiology is instructive. Adam Frank and Woodruff Sullivan writing in *Anthropocene* have attempted to use such an approach to shed light on the chances that humanity may become sustainable in terms of our impact on the planet. In astrobiology, sustainability is a subset of habitability: a planet may be habitable, but it is only sustainable if a human-like civilisation can develop over a long time-scale (Frank & Sullivan 2014, p. 37).

Drake equation

Such is the scale of its field, astronomy is not known for its emphasis on precision. Members of rival disciplines have said that astronomers are usually content with an accuracy “within a couple of orders of magnitude” or hundreds of times the estimate. With that reservation in mind, a key to Frank and Sullivan’s analysis is the classic Drake equation³¹ that was originally developed to predict the chances of other civilisations with radio technology existing within the known Universe. The Drake equation takes the rate of star formation, the fraction of stars with planets, the fraction of planets that are habitable, the fraction of habitable planets likely to contain life, those with intelligent life and those with radio technology to arrive at the number of civilisations that may exist (Ibid, p. 33).

Rather like the IPAT relationship, the Drake equation is not strictly mathematical. For example, contrary to the equation, it is the *net* rate of star formation, rather than the gross rate that determines the number of stars currently in the Galaxy. Stars form, but stars also die. Also contrary to the formula, it is not the rate but rather the total number of stars that must be factored in to find the possible number of intelligent species. As has recently been discovered, stars with planets have been forming in the galaxy long before the birth of our own sun (Campante et al 2015). A modification to the equation conceivably results in an estimate for the mean lifetime of *species with energy-intensive technology* (SWEIT), which frustratingly the article fails to develop. Nonetheless, it does provide an estimate of the commonality of our plight:

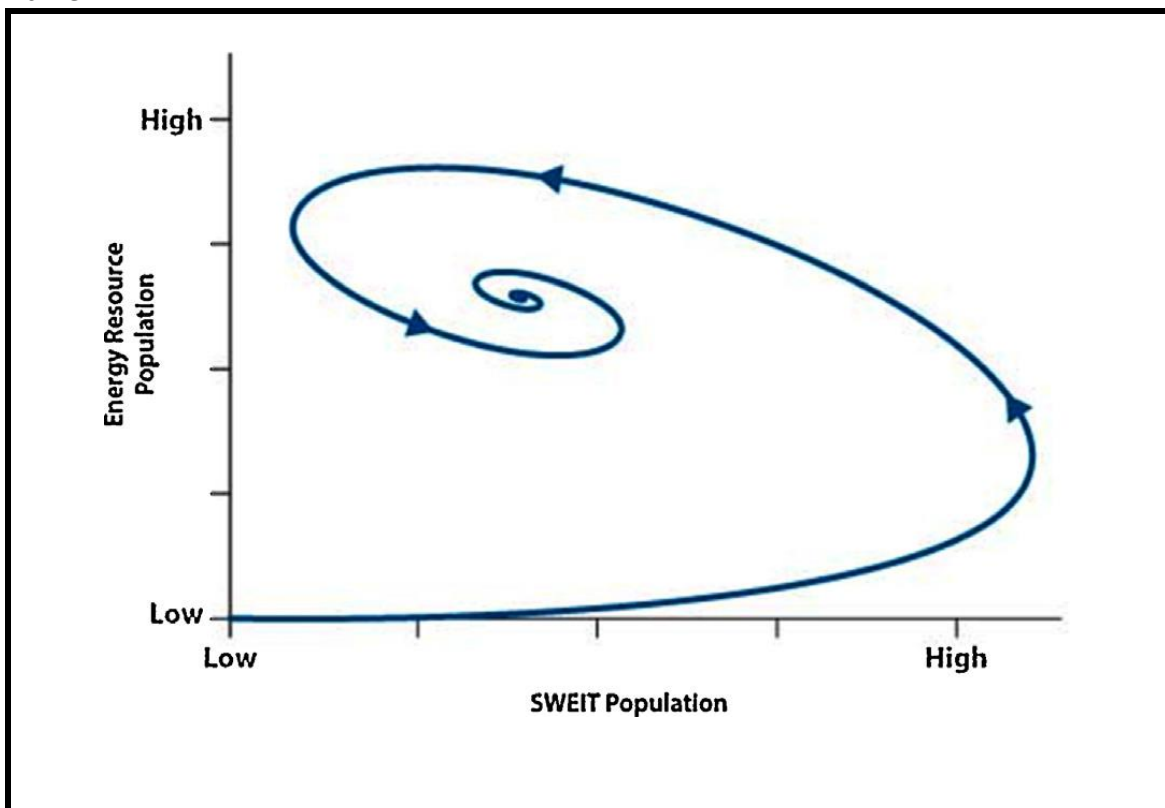
³¹ Attributed to the US astrophysicist, Frank Drake, 1962.

Thus even with the odds of evolving a SWEIT on a given habitable planet being one in one million billion, at least 1000 species will still have passed through the transition humanity faces today within our local region of the cosmos (Frank & Sullivan 2014, pp. 34-35).

Dynamic modelling

The 'transition' Frank & Sullivan refer to is the possibility of the imminent collapse of our civilisation, or worse, the demise of the human species due to our own impact on our habitat. Therefore, and more importantly, the analysis proceeds to compare systems dynamics across two, and three dimensions. The two-dimensional model plots the SWEIT population (N) against energy consumption per capita (E_c) over time. It shows "a stable dynamical system [that] experiences oscillations with decreasing amplitude until a steady state is achieved", as shown in figure 7 below:

Figure 7. Species with energy-intensive technology: population and energy per capita over time



Source: Frank & Sullivan 2014.

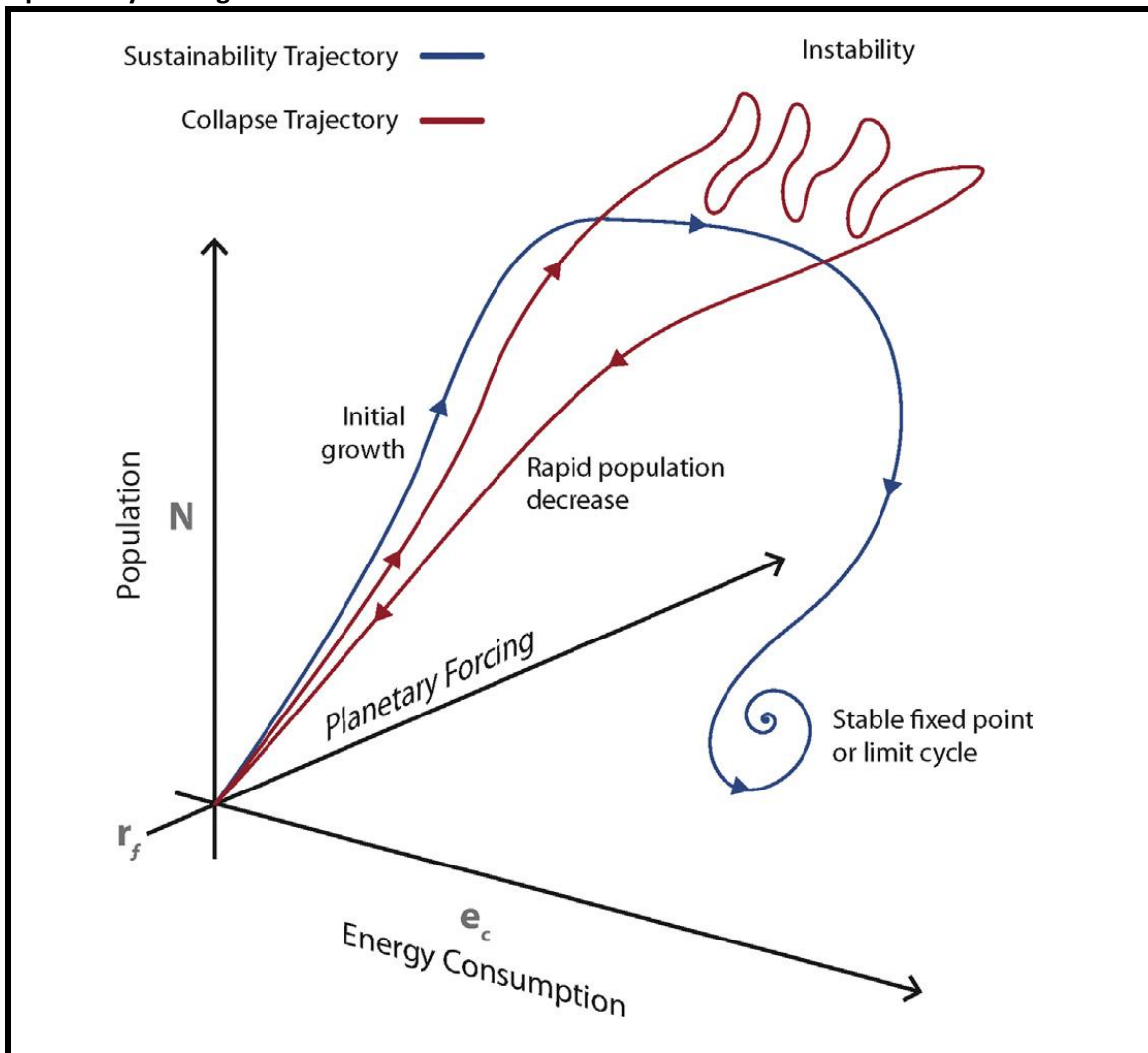
In this two-dimensional model, energy per capita increases to high levels then begins to decline and then oscillate until stability is reached at a moderately high level. At the same time population at first increases to high levels, then declines as energy per capita is still increasing. After reaching a low level, population then varies until stability is reached at a moderate level.

The three-dimensional model, however, includes an estimate of feedback on planetary systems or 'forcing' (F) that result from energy use, such as carbon dioxide increase. It finds current circumstances — high population of the energy-intensive species (N), high energy consumption per capita (E_c) and resultant high feedback on the planetary system (F) — to be unstable, with rapid volatility and deterioration after only a short time. However, *low*

population (N) and high energy consumption per capita (E_c) is stable (Ibid. p. 36) - that is, 'sustainable' in the meaning of the term outlined on page 9.

Figure 8 below shows two possible paths. The 'collapse trajectory' shows a higher population, energy consumption and planetary feedback leading to instability and collapse, while the 'sustainability trajectory' represents a lower maximum population, less energy consumption per capita, reduced volatility and ultimate stability at a lower population but still quite high energy level.

Figure 8. Species with energy-intensive technology: population, energy per capita and planetary forcing



Source: Frank & Sullivan 2014

As this implies, our present energy dilemma may not be unique to our species. Rather, it could be "an issue for petrol-heads across the universe", because having ready access to a highly concentrated stock of fossil fuel creates a dependency that is hard to break. Perhaps we have not been contacted by other advanced civilisations because of this common 'great filter': alien civilisations may have wrecked their planet or run out of fossil fuels before they could make the transition to renewables (Le Page 2014, p. 39).³²

³² This is one possible answer to the 'Fermi paradox': if other civilisations are common throughout the universe, why haven't they contacted us?

UK astrobiologist, Lewis Dartnell, argues that while difficult, it still may be possible to construct an advanced civilisation without fossil fuels by combining hydroelectricity and renewable forest practices. This includes charcoal production for metal smelting with electric cars and public transport. Such an industrial revolution would require “very favourable natural environments” such as Canada or Scandinavia whose rivers enable hydroelectric power and where there are large forests that can be harvested sustainably for thermal energy (Dartnell 2015, para 39). This, however, also implies a much lower human population and reduced consumption.

This conclusion is not so far from Paul Erlich’s 1960s contention – that population is the key factor in the welfare of our species and the planet. Nor is it far distant from the conclusions of the *Limits to Growth* (Meadows et al 1972), which used early computer modelling to estimate the effects of continuing exponential growth.

Lately, computer modelling of impact was featured by complex systems geophysicist Brad Werner, who famously delivered a talk at a large meeting of the American Geophysical Union (AGU) in 2012 with the provocative title *Is the Earth F***ed? - dynamical futility of global environmental management and possibilities for sustainability via direct action activism*. Although a transcript of the talk may not exist, according to reports (Kintisch 2012), it drew on the author’s computer models of humanity’s relationship with environmental systems. According to the abstract – and in contradiction to Hinchcliffe’s assertion³³ – its conclusion is that:

the dynamics of the global coupled human-environmental system within the dominant culture precludes management for stable, sustainable pathways and promotes instability (Werner 2012).

Somewhat more positively, as the talk’s subtitle implies, Werner proposes that sustainability may be possible through “direct action activism”, rather than global environmental management.

However public perceptions of impending catastrophe tend to focus on the impacts of climate change (droughts, floods, hurricanes, rising sea levels), as well as resource depletion and ecosystem degradation, human overcrowding and pandemics, economic collapse, nuclear and biological conflict and “runaway technological change” (Randle & Eckersley 2015, p. 3). Arguably all of these potential catastrophes contain technology as their central factor.

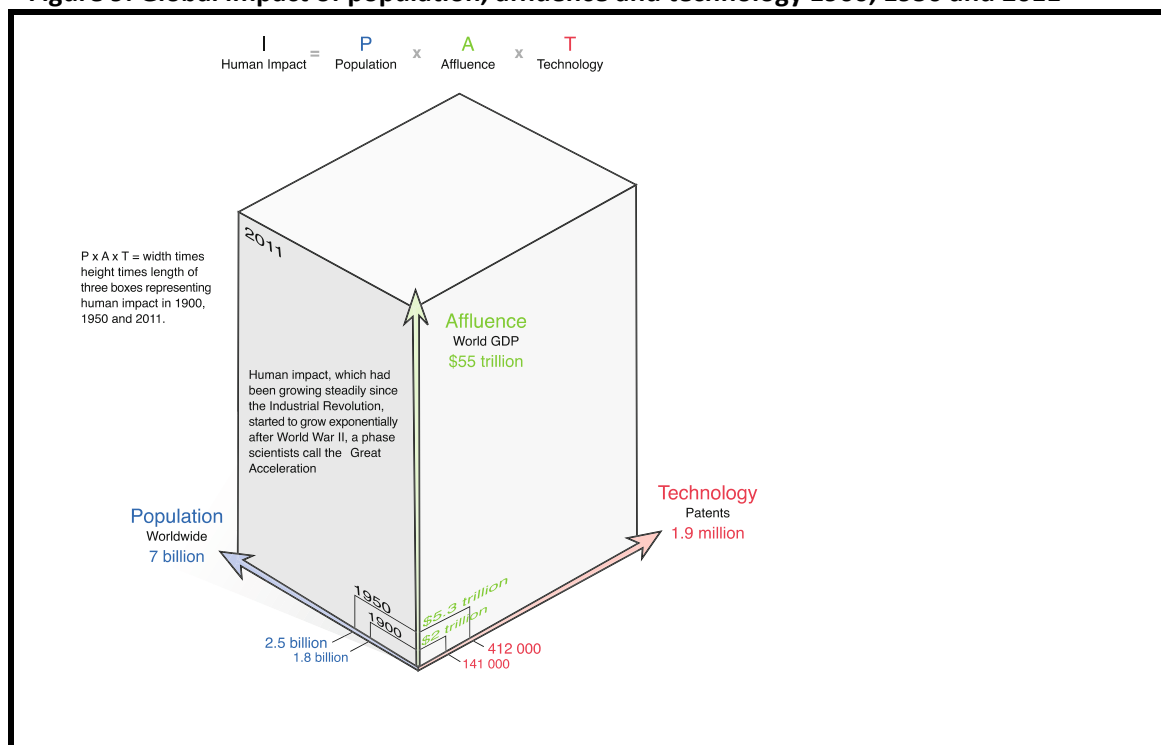
Confusion

Even a landmark paper such as *The Anthropocene: From Global Change to Planetary Stewardship* (Steffen et al 2011) can confuse the factors involved in environmental impact. In order to illustrate the acceleration of environmental impact due to change in population, affluence and technology since the 1950s, the paper recycles a diagram from an Elizabeth Kolbert article in the National Geographic of the same year. The diagram (Ibid, p. 6) purports to show the product of population, affluence and technology between 1900 and 2011, reproduced below as figure 9. It is a vivid illustration of how the three dimensions form a volume of impact. Accepting the units used in the paper (population, GDP in US dollars and patents), a simple calculation shows that the impact of 1950 is about 10.8 times that of 1900,

³³ Hinchcliffe asserted that the answer to any interrogative title will always be ‘No’, which is confounded by Peon’s riposte: ‘Is Hinchcliffe’s rule true?’, which demonstrates that the assertion is false – but only if it is true (Peon 1995).

but the impact of 2011 is an estimated 134 times that of 1950 – and therefore 1442 times³⁴ compared with that of 1900!

Figure 9. Global impact of population, affluence and technology 1900, 1950 and 2011



Source: Kolbert 2011, cited in Steffen et al 2011.

Yet all is not as it seems: there are at least two flaws in this representation. First, affluence (A) should be per person, not total, otherwise population growth is multiplied by itself, which considerably overinflates its value. Second, technology (T) is represented by *patents*, which also tend to increase with population and may not necessarily increase environmental impact. Patents in fact better represent *innovations*, to which they are directly linked, and innovations in the current context often reduce rather than exacerbate environmental impact (Chertow 2000, p. 18). Further, the scope of what is patentable has drastically expanded over the past three decades (Mercurio 2014 p. 4) and the number of patents shown in the illustration (figure 9) appear to be patent *applications*, rather than patents granted, which again inflates results.

But even accepting that 'patents' is a valid cipher for T (technology), when total affluence is reduced to affluence *per person* and patents are reduced to patents *per person*, the resultant impact in 2011 is 95 times times that of 1900. This is still a very large figure, but considerably less than the 1442 times implied by the illustration. The 'per person' approach is consistent with the Holdren-Erlich formulation that proposed "environmental degradation = population x consumption per person x damage per unit of consumption" (Holdren & Erlich 1974, p. 282). It is consistent with all other formulations, which involve per capita consumption, production or economic activity (Chertow 2000). Professor Steffen disagrees with this assessment,³⁵ saying that much of the increase in GDP in that time was not due to population increase because it largely occurred in OECD countries with low population growth rates, and that the

³⁴ 1900: 1.8 billion X 2 trillion X 141, 000, whereas 2011: 7 billion X 55 trillion X 1.9 million. Ratio: 3.89 X 27.50 X 13.48 = 1442 times that of 1900.

³⁵ Personal email of 26 September 2014.

diagram was only for illustrative purposes, not meant to be mathematically rigorous. Nevertheless, while this is an important point, the illustration remains misleading.

Relative impact

In terms of the impact of humanity compared with other species, the US marine biologists Charles Fowler and Larry Hobbs have shown just how much of an outlier species we humans are. Their Royal Society paper, *Is humanity sustainable?* (2003), measures the impact of humans compared with various other species in biomass consumption, CO₂ production, geographical range and population size. They compare humanity with seabirds, marine mammals, fish and terrestrial mammals. The differences in impact are vast. For example:

[the impact of] the human population is over two orders of magnitude [hundreds of times] greater than the upper 95 per cent confidence limit of populations for non-human mammalian species of similar body size, and over four orders of magnitude [36,760 times] greater than the mean (Fowler & Hobbs 2003, p. 2580).

Their conclusion, that the human species is abnormal and that atypical elements of human ecology “are among the primary factors” contributing to the environmental problems the world now faces, is hardly surprising. What is surprising is the enormous scale of that abnormality. However, the features of that abnormality are equally important, discussed below under *extinctions*.

Extinctions

Apart from relative consumption and waste production, our impact on biodiversity is profound. The title of Carson’s 1962 classic *Silent Spring* evoked a world devoid of animal life due to synthetic pesticides. While her work led to the banning of DDT and other biocides, the spectre of what has been termed ‘biosimplification’ still haunts our planet. In 2014 Peter Fisher wrote of a future eerie silence:

Some have predicted that, within just two or three centuries, we could be alone except for pets, chickens, livestock, and an unknown suite of microbes and freeloaders such as mice and cockroaches. For a sneak preview of this “biosimplification”, look no further than the swathes of European countryside where there has been a crash in bird populations – no songs, no glimpses of plumage, just an eerie silence – as a result of the wholesale ripping up of hedgerows, draining of wetlands and ploughing over of meadows robbing farmland birds of their homes and sustenance in order to boost farming production. That would leave us living in a drab, crummy landscape where surviving native plants cower in small niches away from the weeds; zoos exhibit a lost fauna; and biophilia is reduced to watching carp (Fisher 2014, paras. 19-21).

In the seas, climate change is a major driver of biodiversity loss until 2100, as oceans warm and marine species follow thermal niches (Molinos et al 2015, p. 1). Overall, threats to biodiversity and whole species on both land and sea are due to over-hunting, over-fishing and over-farming, or in blunt technological terms “guns, nets and bulldozers” (Maxwell et al 2016, p. 143).

All this is in contrast to the Enlightenment’s Thomas Jefferson, who was of the firm view that nature never let any species become extinct (Gerbi 2010, p. 257). Of course then North America was swayed to 40 million or so bison and as well as perhaps five billion prairie dogs,

both now reduced to pathetic remnants³⁶ of that earlier “infinite” (Worster 1993, p. 4). At least, what was once 40 million white-tailed deer, reduced to about half a million by 1900, have since rebounded to be about 15 million in the same habitat (Smith 1991, p. 5).

A related concept is the idea of ‘great extinctions’, popularised by the National Geographic and New Yorker writer, Elizabeth Kolbert in *The Sixth Extinction: An Unnatural History* (2014). The fossil record shows that there have been five brief eras in which many forms of life on the planet became extinct; the extinction of the dinosaurs and the rise of mammals about 60 million years ago were the most recent – until now. This sixth great extinction is driven by humanity and industrial technology, and is extremely rapid, about “a thousand times the rate of background extinctions” (Pimm et al 2014). This is discussed under chapter 5 on *affluence* insofar as it relates to consumption.

Whilst extinctions occur due to chance natural causes, only the human species drives other life forms to extinction with an organised intense and ruthless brutality. The passenger pigeon, once the most common avian species in North America that flew in flocks of millions, finally was made extinct over a century ago. According to the Encyclopedia Smithsonian (2014), this species once constituted 25 to 40 per cent of the total bird population of the US. There were estimated to be between three and five billion of them at the time Europeans reached America. That extinction was by direct human agency:

The professionals and amateurs together outflocked their quarry with brute force. They shot the pigeons and trapped them with nets, torched their roosts, and asphyxiated them with burning sulfur. They attacked the birds with rakes, pitchforks, and potatoes. They poisoned them with whiskey-soaked corn (Yeoman, 2014).

Using industrialised methods that exploited the new technologies of the railway and the telegraph, the birds were slaughtered more intensely even as their numbers dramatically declined, until the final one, named ‘Martha’, that withered away the last years of her life in the Cincinnati zoo until her death in 1914.

The Tasmanian tiger (thylacine) is an even swifter and more recent extinction. A top predator that had co-existed with an isolated indigenous human population for forty thousand years, it was wiped out in the space of little more than a century by the arrival of Europeans, who saw it as a threat to farming. European settlement began in Tasmania in 1803. The last wild thylacine was shot in 1930 and the very last of the species, called Benjamin, died in a Hobart zoo in 1936 (Shreeve 2013).

Many larger fauna extinctions at our hand have occurred on islands, as in Tasmania. The human wave that populated the Pacific over the last few thousand years meant the end of much animal life, not only many bird species in Hawaii for example, but a species of eagle and all of the genus moa in New Zealand during the twelfth century, when it became the last land on Earth to be permanently occupied by humans. In the Indian Ocean, the extinction of the dodo in Madagascar in the seventeenth century is infamous. On an island there is no refuge, no chance of escape, once humans assert it as their territory.

The 2014 report from the World Wildlife Fund, *Living Planet: Species and spaces, people and places*, indicates that between the years 1970 and 2010 more than half of all vertebrate

³⁶ Bison numbers were down to 1091 by 1889, and have rebounded to about 500,000 according to Defenders of Wildlife (www.defenders.org/bison/basic-facts). Prairie dog numbers have been reduced by 98 per cent since 1900 (National Geographic: <http://www.nationalgeographic.com/features/98/burrow/pdog.html>).

species (fish, amphibians, reptiles, birds and mammals)³⁷ have been made extinct. Already the human species together with our domesticated animals form 97 per cent of all vertebrates on Earth by weight. 'Wild' vertebrates form only three per cent (Smil 2011, cited in Hamilton 2014, p. 1). According to the report (WWF 2014, p. 20), the main factors³⁸ in these extinctions are over-exploitation (37 percent) habitat degradation (31 percent) and habitat loss (13 percent). Other lesser factors are climate change (7 percent), invasive species or genes (5 percent), pollution (4 percent) and disease (2 percent). Over-exploitation is a product of increased consumption based on affluence, or else increased population, or both. Degradation and loss of habitat are similarly influenced.

This stark picture echoes the concept of the 'Eremozoic era', originally found in biologist EO Wilson's book, *The Creation: an appeal to save life on Earth* (2006). While the destruction of fauna that began when human ancestors began eating meat has continued and increased, it is now at cataclysmic proportions. The megafauna on each continent began to disappear as soon as humans arrived, such that its destruction marks the spread of humanity through the planet. In Australia the animals included the giant kangaroo and the diprotodon. Most recently, the giant Moa³⁹ of New Zealand – the final land settled by humans – were eliminated entirely in less than 200 years after the arrival of humans around 1200 AD (Flannery 1994, Roberts & Jacobs 2008). The Eremozoic era will be a consequence of the sixth great extinction, when the Earth will lack nearly all vertebrate life due to the impact of human activities. This permanent loss will probably reach final Mesozoic proportions by the end of this century, or much sooner according to Ceballosa, Ehrlich & Dirzob (2017), who have deemed it a "biological annihilation". Humanity has begun to enter Wilson's Eremozoic era — the *Age of Loneliness*.

Is this destruction intentional? Steven Freeland (2015) points out that the environment is often a silent victim of warfare. Like rape once was, it is regarded as an inevitable consequence of mass conflict. Dutch ecologist, Sanne van der Hout, asks a related question in her 2014 article *Is de natuur partner of jachtgrond? – Is nature a partner or a hunting ground?* (van der Hout, 2014). However, this devastation of species and habitats progressively looks more and more like an intentional organised conflict rather than just the unfortunate result of overconsumption or a by-product of human warfare. According to legal geographer Bronwyn Lay's paper *Ecocide as War*, ecological destruction may be "a deliberate power strategy and attack against nature, not as collateral damage, but nature as centre stage both as participant and victim in warfare" (Lay 2014, p. 1). She asserts that "the mass destruction of forests, rivers and soil pollution increasingly resemble battlefields: policed by privatised 'armies' masked as corporate security" (Lay 2014, p. 4). Certainly this rings true for the manner in which native forests are treated in for example, Tasmania and New Zealand. In these places entire hillsides are laid waste to monochrome grey mud and fibre like the battlegrounds of Flanders, torched by firebomb then poisoned with chemicals to kill any wildlife that may return to nibble on a new-sprouting alien seed.

If ecocide were an international crime, then many now unmonitored areas around the world would come under legal scrutiny as crime sites rather than regarded in regulatory terms as the consequence of 'environmental degradation'. If 'nature' thus becomes a legal subject, as 'humanity' has become after the Second World War and the invocation of the crime of genocide, then recognition of ecocide would change the current paradigm from potential

³⁷ Based on the Living Planet Index, calculated using trends in 10,380 populations of over 3,038 vertebrate species.

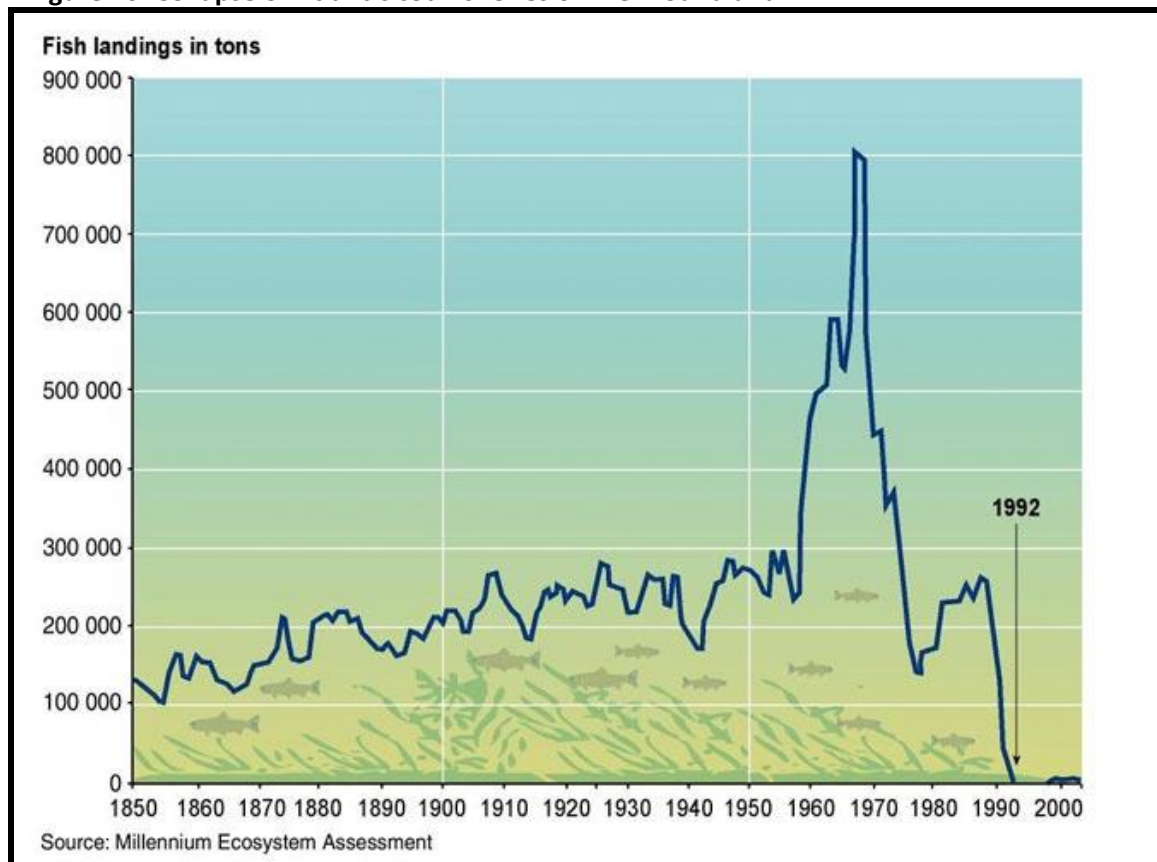
³⁸ Not all populations were assessed, but these factors were identified in 3,430 different species populations.

³⁹ The word 'Moa' throughout the Pacific now has a related but reduced meaning: it means 'chicken'.

regulation to “resultant rights and protections” (Ibid). In fact, the international crime of ecocide was proposed to be included as one of five *Offences Against the Peace and Security of Mankind* in a 1996 UN draft that also listed *Genocide, War Crimes, Crimes Against Humanity* and *Crimes of Aggression* that have since become International Crimes Against Peace under the jurisdiction of the International Criminal Court (Higgins 2012, p.10).

While extinctions are global, populations can be decimated locally. Probably to their benefit, Atlantic cod survive in some seas, perhaps because they do not share terrestrial territory with humans. Cod have been a food staple of Europe for hundreds of years. The Grand Banks, off Newfoundland, were regarded as a limitless resource that were exploited to sustain a growing human population. As figure 10 below shows, the amount of cod landed from this area gradually increased during the nineteenth and twentieth centuries, until during the 1960s catches were trebled to a peak of 800,000 tons a year. The catch then suddenly collapsed in two stages, until 1992 when there were virtually no cod left and the fishing grounds were closed. Again it was industrialisation of the industry that enabled the huge increase in catch during the 1960s and its subsequent exhaustion. Combined with poor regulation, resulting in increased competition, the fishery was doomed (Kurlansky, 1998).

Figure 10. Collapse of Atlantic cod fisheries off Newfoundland



The Grand Banks story is a particular example of the industrialised approach to fishing generally since World War II, using high-powered diesel engines, sonar, vast nylon nets, and satellite imagery to locate and harvest increasing amounts of fish. Since the war, “fishing was transformed from a local endeavor into a global one” using much larger ocean-going ships and the “permanent occupation of marine ecosystems, instead of the local raids practiced by previous generations” (Greenburg & Worm 2015, para 8). This impact is such that despite increased use of active fishing technologies such as trawling and purse seining globally there

has been a halving of fish caught *per fisher*, from five to two and a half metric tons a year between 1970 and 2012 (World Bank 2017b, p. 14).

In contrast with the Grand Banks, however, the Atlantic cod fishery asserted by Iceland during the three 'Cod Wars' of the 1950s-1970s with the UK has remained sustainable and is certified as such under Food and Agriculture Organisation (FAO) guidelines (IRF 2014). The result of the Cod Wars was to give Iceland exclusive rights to manage an area 200 nautical miles (370 km) from its coast, a result ultimately achieved through international arbitration that followed aggressive confrontations between the British navy and Icelandic trawlers. Its sustainability was achieved due to Iceland's exclusive rights, and because the fishery is one of Iceland's few resources, which implies a strong focus on its regulation. Iceland has a small tight-knit population⁴⁰ who understand its importance and support its management. There is also increasing evidence that stocks of Atlantic Cod are again becoming viable in the North Sea following the implementation of fishing bans in that area (Smith 2015). Therefore, Atlantic cod do not risk extinction of the entire species, but their remnant population off the Grand Banks remains closed to further fishing.

These examples illustrate how new technologies as well as the pressure of a growing human population were involved in increasing environmental impact during the last two centuries. However, Chertow (2000) shows how the impact of 'T' in the IPAT has increasingly become regarded as benign or more favourable in reducing impact since the identity was formulated nearly fifty years ago. At first, technologies were used to clean up the results of other production technologies "at the end of the pipe". Later, newer technologies were developed that were less harmful in their composition. Also some technologies are like Janus. For example, Greenburg & Worm (2015) point out that the same electronic technologies that are used to track schools of fish are now also used to track fish poachers, an increasingly important endeavour as fish stocks decline towards unsustainable levels and marine reserves are created in response.

Yet even if newer processes are less harmful and some technologies beneficial, Chertow articulates an important conundrum facing policy on environmental impact due to the relationship between population and technology. Does an increased population call for improved technology that can reduce environmental impact, or does an improved technology allow an increased human carrying capacity? While there has been a productivity revolution in both energy and resources since the IPAT identity was formulated, new technologies allow for more of us, but eventually too many of us may be overwhelming: "Does technology merely delay the inevitability of environmental destruction, or is better technology our best horse in the race toward sustainability?" (Chertow 2000, p. 18). This is a basic question that this dissertation attempts to answer.

The rate of extinction may be compared with the natural rate of speciation, the evolutionary creation of new species. Comparisons of the two estimated rates are jaw-dropping. Robert May, writing in *Science* attempts to quantify the possible number of species on Earth. Through various extrapolations he produces numbers up to perhaps 50 million, although he "will not trust any estimate" without further research. Uncertainties are due to the existence of myriad very small species with body sizes less than a millimetre, which have received "relatively little attention from taxonomists" (May 1988, p. 1447-1448). Ehrlich & Pringle (2008, pp. 330-331) estimate there is of the order of tens of millions of species on Earth, and that estimates of extinction rates "are similarly imprecise". They cite May et al (1995) saying that while only a

⁴⁰ Around 315,000 people according to the 2011 national census.

little more than a thousand extinctions have been certified in the past four centuries, “this is a small fraction of the true number” of extinctions because our knowledge of biodiversity is “pitiful”. Further, “current extinction rates vastly exceed background ones, perhaps by two to three orders of magnitude”, or hundreds to thousands of times.

But while he is unable to establish the number of species with any precision, in a coda to the article, May remarks that rates of extinction have roughly matched rates of speciation for most of the period of life on Earth. Assuming that half of all existing species evolved within the last 100 million years and that half of them will become extinct within the current century, then contemporary extinction rates are around a million times faster than contemporary rates of speciation (Ibid, p. 1448).

More recent estimates of the number of species appear diminished by comparison. The biologist and ‘ecopragmatist’, Stewart Brand, for example, in *Rethinking Extinctions* (2015) casually mentions “the 1.5 million species so far discovered, and most of the estimated 4 million or so species yet to be discovered”. However because he is writing in the context of the IUCN red list of endangered species,⁴¹ the apparent inconsistency between his estimates and those of May, Erlich and Pringle are plausible: May et al discuss *all* species, including those at the micro-level. By contrast, Brand seems to be discussing larger organisms, particularly mammals, birds, reptiles and amphibians as well as fish, insects, molluscs and plants, especially those that have been studied to varying degrees.

Figure 11 below shows the estimated number of (larger) species as at 2007 according to the IUCN, a total of 1,388,137 species in eight groups. Of those, 15,790 are threatened, or just over one percent of the species studied. Dell’Amore (2013), not unreasonably based on the IUCN figures, mentions that 20,000 species are now facing extinction. And irrespective of extinctions, the World Wildlife Fund’s Living Planet Index (LPI) shows a 58 per cent drop in overall numbers of vertebrates between 1970 and 2012, or two per cent per year (WWF 2016, p. 6).

Figure 11. Threatened species

Group	Species	Critically endangered	Endangered	Vulnerable	Total Threatened
Mammals	5,416	163	349	582	1,094
Birds	9,956	189	356	672	1,217
Reptiles	8,240	79	139	204	422
Amphibians	6,199	441	737	630	1,808
Fish	30,000	254	254	693	1201
Insects	950,000	69	129	425	623
Molluscs	81,000	268	224	486	978
Plants	297,326	1,569	2,278	4,600	8,447
Total	1,388,137	3,032	4,466	8,292	15,790

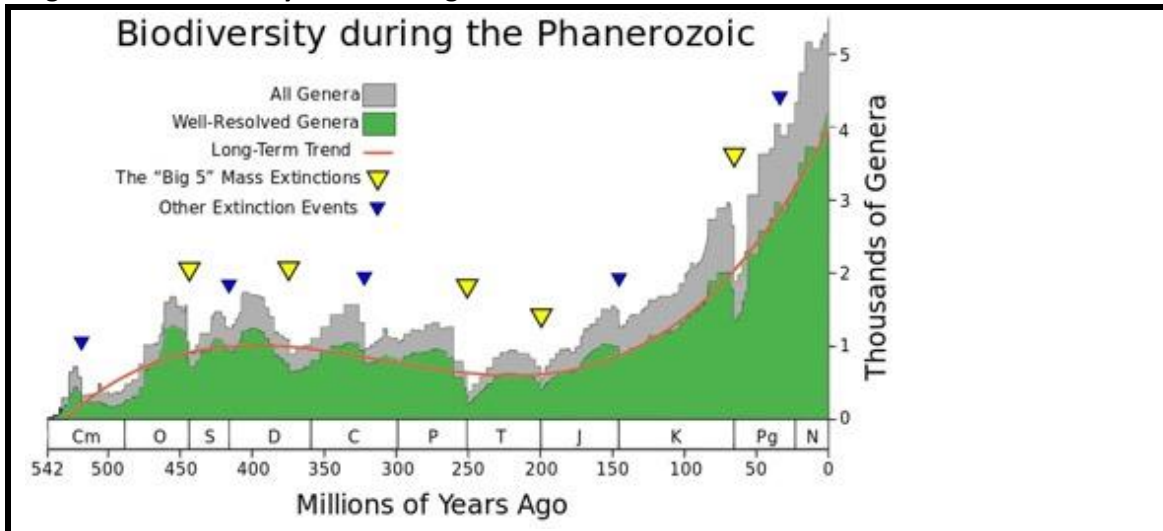
Source: 2007 IUCN Red List

The key assertion of Brand’s article though, is that biodiversity is continuing to *increase*, rather than dramatically plummet as the others suggest. In support of this he includes a graph (figure

⁴¹ Although at one point, the IUCN itself says: “According to the Millennium Ecosystem Assessment, the total number of species on Earth ranges from five to 30 million and only 1.7–2 million species have been formally identified” (<<http://iucn.org/iyb/about/>>).

12) produced by University of Chicago palaeontologists Sepkoski and Raup⁴² that shows the five past great extinctions as substantial, but ultimately mere blips in a long-term trend increase in biodiversity based on the fossil record of *genera*, the level above species:

Figure 12. Biodiversity: number of genera over time



Source: Sepkoski & Raup, University of Chicago, 2002, and cited in Brand 2015.

This result, based on material from two authoritative palaeontologists, is counter-intuitive and appears to completely contradict the findings of May, Fisher, Erlich & Pringle, Kolbert and Dell'Amore. There are reasons for this, however. First, increasing biodiversity as suggested by the graph still allows for declining populations. Whether there are a billion passenger pigeons or one Martha, there is still one species in existence. Now there are far fewer cod in the Grand Banks than before, but the number of species of such fish remains the same: one. Palaeobiologist Professor Tim Wootton of the University of Chicago's Ecology and Evolution department adds that the graph may be distorted. More recent indicators tend to show higher levels of biodiversity due to methodology: fossil preservation is better in more recent material and also there are wider sources of information in later periods (called "the pull of the recent"). And "some recent papers" show "little sustained increase in diversity once sampling effects are considered".⁴³

But most tellingly, Professor David Jablonski, also of the University of Chicago and former associate of Sepkoski and Raup, points out that the data in figure 12 "are binned into million year or larger increments" and that the curve is at genus rather than species level, so that anthropogenic extinctions of the last 12,000 years would be undetectable at the scale it encompasses.⁴⁴ So Brand has misinterpreted the information in figure 12. There is no doubt that over the past *millions* of years, biodiversity has continued to increase. But over the latest few *thousand* years it has almost certainly declined – precipitously – at human hand.

Pollution

Contamination from pollutants has been with us for a long time. French and US geologists Sungmin Hong and associates found evidence of lead pollution in ancient times – considerably before the advent of Industrial Revolution:

⁴² It is from Sepkoski J, 2002.

⁴³ Wootton, personal email of 25 April 2015.

⁴⁴ Jablonski, personal email 25 April 2015.

Analysis of the Greenland ice core covering the period from 3000 to 500 years ago—the Greek, Roman, Medieval and Renaissance times—shows that lead is present at concentrations four times as great as natural values from about 2500 to 1700 years ago (500 B.C. to 300 A.D.). These results show that Greek and Roman lead and silver mining and smelting activities polluted the middle troposphere of the Northern Hemisphere on a hemispheric scale two millennia ago, long before the Industrial Revolution. Cumulative lead fallout to the Greenland ice sheet during these eight centuries was as high as 15 per cent of that caused by the massive use of lead alkyl additives in gasoline since the 1930s. Pronounced lead pollution is also observed during Medieval and Renaissance times (Hong et al 1994).

Apart from the longevity of the phenomenon, the operative word here is ‘cumulative’. It is the accumulation of pollutants, or the incapacity of the biosphere to absorb their flow, that essentially defines them as pollutants. And arguably, it was the exposition of cumulative effects by two women that defined modern environmentalism. While the American Rachel Carson pioneered the modern environmental movement with her 1962 book *Silent Spring* on the effects of pesticide accumulation, the so-called ‘Japanese Carson’, Ariyoshi Sawako, added new dimensions to the concept in her novel *Fukugō Osen* (‘Compound Pollution’ or ‘Cumulative Pollution’) that took Japan by storm in 1974. In another parallel, Ariyoshi’s book was first published in serialised form in a major newspaper, the *Asahi Shimbun*, as Carson’s had been in the *New York Times*⁴⁵ a decade earlier. Ariyoshi’s book sparked intense public debate about environmental toxins, such as pesticides and herbicides, synthetic detergents and chemical food preservatives. Such was the success of the serialisation that the newspaper published more than sixty articles about cumulative pollution during the subsequent year (Hartley 2014).

The impact of *Fukugō Osen* was magnified by the then recent awareness of the outbreak of the lethal ‘Minamata disease’ from the late 1950s to the 1970s. The disease, which had profound neurological effects similar to cerebral palsy, was found to be due to intense concentrations of heavy metals in shellfish in Minamata Bay and its surroundings on the West coast of Kyushu. The concentration of heavy metals was due to industrial pollution. While tens of thousands of people were affected and more than 1500 died from the toxins, Japanese authorities and the business concerned moved at glacial pace to rectify the source of the problem.

Before World War 2, “smoke, sewage, and soot were the main environmental concerns” as they had been since the Middle Ages (Chertow 2000), but it was the revolutionary thinker Barry Commoner, who observed that there had been a remarkable change since then:

most United States pollution problems are of relatively recent origin. The postwar period, 1945–46, is a convenient benchmark, for a number of pollutants—man-made radioisotopes, detergents, plastics, synthetic pesticides, and herbicides—are due to the emergence, after the war, of new productive technologies (Commoner 1972a, p. 345).

These pollutants were not only being produced at vastly increasing rates, but they were artificial – synthetic – that were alien to the structure of the biosphere and therefore difficult to break down and absorb. Hence they tended to accumulate in ever-increasing concentrations.

⁴⁵ There was an alliance between the two newspapers until 2010, during which the *Asahi Shimbun* produced a version of the *International Herald Tribune* in English in Japan. This may have been a factor in Asahi’s decision to serialise Ariyoshi’s book.

However, pollution is not just a local or national issue. Its distribution is global. Former World Bank economist and US Treasury Secretary under Clinton, Larry Summers, infamously once asked in an email to Bank staff if pollution should be shifted to poor countries:

shouldn't the World Bank be encouraging more migration of dirty industries to the LDCs [less developed countries]?...The economic logic behind dumping a load of toxic waste in the lowest wage country is impeccable, and we should face up to that...Under-populated countries in Africa are vastly under-polluted; their air quality is probably vastly inefficiently low compared to Los Angeles or Mexico City...The concern over an agent that causes a one in a million change in the odds of prostate cancer is obviously going to be much higher in a country where people survive to get prostate cancer than in a country where under-five mortality is 200 per thousand (Summers 1992, p. 66).

While it has been argued that the email was sardonic, or that it was 'economically impeccable' (Johnson et al 2007, p. 398), the idea has failed to find overt support. But as a matter of reality, while not so much to Africa, much polluting industry has shifted to Asia. For example, the ship breakers of Bangladesh are renowned for their lack of protection from pollutants such as asbestos. In China, power generation and associated manufacturing has displaced much of the industry of the West, but at the cost of considerable pollution.

Contamination also takes other forms. For example, pesticides may also be contributing to the decline of bees, which are essential to the pollination of many crops (Saunders 2016). Derived from nicotine as their name suggests, neonicotinoids are widely used including in around 95 per cent of the US corn crop. Part of their appeal is that they are simple to use. After seed planting, the water-soluble pesticide is absorbed by the growing plant. But when bees feed on the nectar of these flowering crops, they are exposed to the pesticide. Bees may even prefer treated crops due to the effects of their nicotine content⁴⁶ (Philpott 2016). 'Neonics' as they are often called are also sprayed, which risks direct exposure for bees and other insects. According to a recent US Environmental Protection Agency report,

for all crops and application methods where on-field exposure is expected, values exceeded risk levels of concern [LOCs]...For all use patterns where residue data were available, LOCs were exceeded (USEPA 2016, p.18)

And even in the deepest ocean, artificial persistent organic pollutants (POPs)⁴⁷ have been found to be accumulating in marine amphipods, at depths of 7,000 to 10,000 metres (Qui 2017). Nowhere is safe from chemical contamination.

Air

According to the World Health Organisation (WHO), air pollution causes more deaths worldwide than AIDS, diabetes and road injuries combined and is responsible for "one in eight of total global deaths" or more than seven million people each year, making it the single largest environmental health risk on Earth (WHO 2012). The impacts of air pollution fall mainly on the poor and disadvantaged. People living near major roads or large industrial sites are particularly affected, as are many people in rural areas. Nearly 84 per cent of all people live with ambient concentrations of fine particulates greater than WHO guidelines,⁴⁸ and the

⁴⁶ The effects might be described as a 'mild buzz' (pun intended).

⁴⁷ These include polychlorinated biphenyls used in plastics and antifoulants as well as polybrominated diphenyl ethers, used as flame retardants, which are either banned or being phased out.

⁴⁸ Fine particulates are less than 2.5 microns diameter; WHO guidelines allow up to ten micrograms per cubic meter.

number of people exposed increased by ten percent between 1990 and 2010 (World Bank 2015b, p. 63). Pollutants such as sulphur dioxide, nitrous oxides and particles resulting from energy generation, industry and motor vehicles have serious health and environmental consequences, according to the American Meteorological Society (AMS).

Air pollution has been a public issue for centuries, but effective action has been limited to mainly rich countries since World War 2. In 1306 King Edward I of England proclaimed a ban on the use of sea coal⁴⁹ in London due to the smoke it caused. The first attempt to control air pollution in the US was in 1881 when Chicago and Cincinnati enacted clean air legislation and other cities followed. Around 1900, the federal Bureau of Mines briefly created an *Office of Air Pollution* but the office closed soon after due to inactivity. During the late 1940s serious smog incidents raised political concern to new levels, resulting in the 1955 US Air Pollution Control Act, the first of several clean air laws that are still in effect. Figure 13 below lists some of the important air pollution events between the 1940s and 1990.

Figure 13. Air pollution regulation 1948-1990

1948.	Smog in Donora, Pennsylvania US remains for five days causing 20 deaths.
1949.	USSR enacts air pollution law and establishes a department to monitor emissions.
1952.	Smog in London UK lasts for four days causing about four thousand deaths. ⁵⁰
1955.	US passes Air Pollution Control Act.
1956.	UK passes Clean Air Act.
1970s	Lead concentrations in products restricted and lead-based paints banned outright in US.
1974.	The catalytic converter is introduced to cut motor vehicle emissions in the US.
1974.	Discovery that chlorofluorocarbon (CFC) refrigerants destroy the ozone layer.
1978.	US bans CFCs.
1980s	Radioactive radon gas found to cause thousands of cancer deaths each year.
1980s	USEPA begins radon research program
1984.	Thousands killed or injured in Bhopal India, due to isocyanate gas leak from Union Carbide plant.
1985.	Hole in the ozone layer discovered by the British Antarctic Survey, attributed to CFCs.
1985-95.	Leaded petrol (gasoline) phased out in the EU and OECD countries.
1986.	US proposes stronger lead restrictions in a wide range of products.
1986.	US and Canada recognise acid rain as “transboundary” issue, industry clean air programs increased.
1988.	Alternative motor fuels act passed in US. Government fleet begins use of methanol and ethanol.
1989.	UN <i>Montreal Protocol</i> phases out CFCs in favour of less harmful substitutes. ⁵¹
1990.	US <i>Pollution Prevention Act</i> passed, dealing with pollution at source.

Source: American Meteorological Society, 2015.

⁴⁹ ‘Sea coal’ was mined from easily accessible deposits on coastal cliffs, especially along the Yorkshire coast.

⁵⁰Source: UK Met Office. <<http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/case-studies/great-smog>>.

⁵¹ Those substitutes, hydrofluorocarbons (HFCs), also proved problematic and are to be phased out from 2016, in favour of hydrofluoroolefins (HFOs), that rapidly degrade in the lower atmosphere (Rae 2016).

In 2016, India announced plans for 56.5 per cent of its electricity capacity to be from non-fossil-fuelled sources by 2026-27 (CEA 2016, xxv). In 2017, China announced cancellation of plans to build an additional 103 coal-fired power plants. This represented more than the entire coal-fired capacity of Germany (Forsythe 2017).

Carbon

Carbon pollution is largely unnoticeable because its main vehicle, the gas carbon dioxide (CO₂), is both colourless and odourless, as well as safe to breathe providing there is sufficient oxygen present. Its indirect effects due to increasing concentrations are nevertheless highly significant, both in its impact on the atmosphere as the major greenhouse gas and on the oceans as the major acidifier.

During the nineteenth century it was known that atmospheric carbon dioxide was increasing and that it could cause global warming through the greenhouse effect. In 1895 the Swedish chemist Svante Arrhenius quantified the impact showing that a doubling of its proportion in the atmosphere would result in a global temperature increase of between five and six degrees Celsius (Arrhenius 1896, p. 266). However, he did not specifically link the CO₂ increase with the burning of fossil fuels.

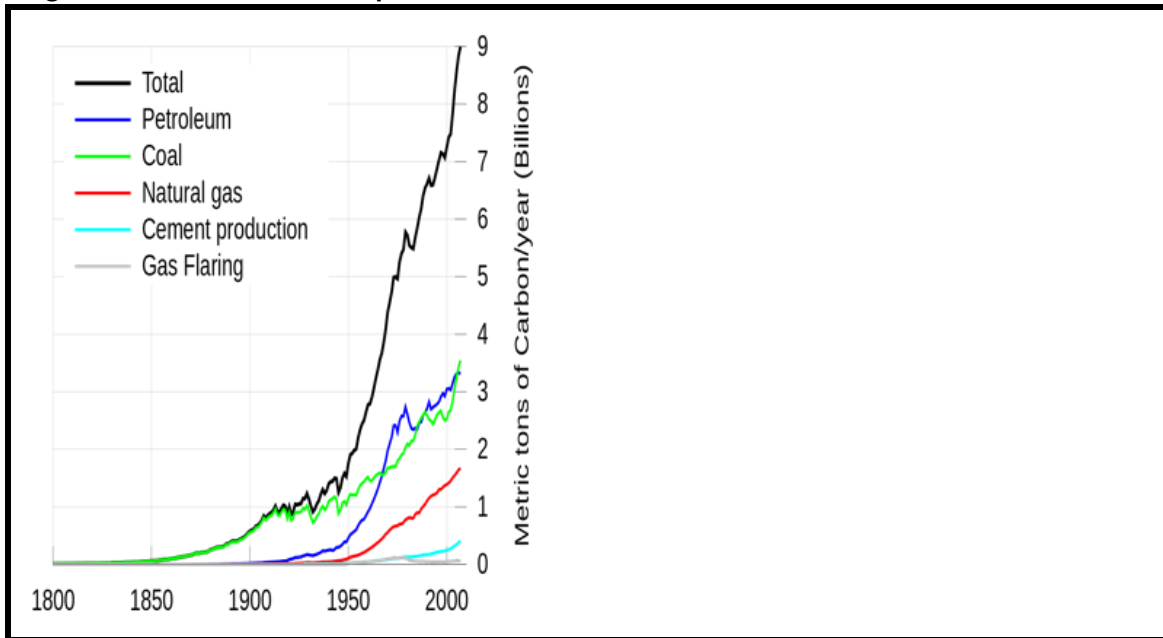
Nevertheless, over the next century the link and its magnitude became clear. After winning the Pulitzer prize for her book *The Sixth Extinction*, Elizabeth Kolbert, was interviewed by the New York Times. She spoke of how fast we are changing the world:

When we use fossil fuels, we are reversing geological history by taking organisms that were buried millions of years ago and pumping their carbon back into the atmosphere at a very fast rate...Humans have sped up the rate by which we change the world, while the rate at which evolution adapts is much slower. There's a mismatch between what we can do and what nature can sustain (Dreifus 2014).

Pumping ancient stored carbon back into the atmosphere at millions of times the rate it was fossilised is of course the source of global warming now experienced throughout the biosphere. The issue is how to de-carbonise the economy before the impact of resultant global warming brings irreversible change including accelerating sea level rise, climate disruption, habitat destruction and even more extinctions.

As shown in figure 14 below, the main sources responsible for global carbon pollution are petroleum and coal equally, both about a third of the total – around 10 billion tonnes per year – plus natural gas at about 17 per cent and cement production at about five percent of global carbon pollution:

Figure 14. Sources of carbon pollution

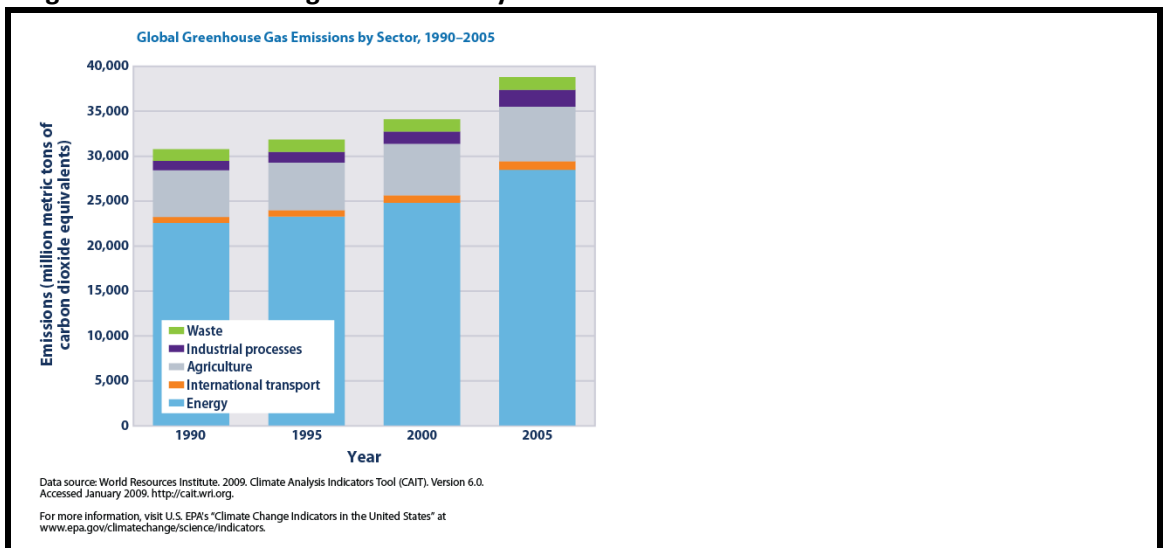


Source: Marland, Boden & Andres, 2007

Cement is the key ingredient of concrete, the ubiquitous building material of modernity and by volume second only to water in amount consumed world-wide (WBCSD & IEA 2009, p. 2). While the rate of carbon emissions per tonne of cement has fallen since 2000, without mitigation total carbon emissions from this industry will still rise by mid-century, such is the likely increase in production (Ibid).

Still, the energy sector has by far the greatest emissions. Figure 15 below shows the relative contribution to global carbon pollution and other greenhouse gases by sector. It demonstrates that not only does energy production emit the most greenhouse gases, but emissions are growing the most in that sector. Much of this energy production is of course grid electricity from thermal power plants that are fired by coal and gas. Where grids do not exist or are unreliable, much electricity is produced from diesel generators that use petroleum-based fuel.

Figure 15. Greenhouse gas emissions by sector



Source: World Resources Institute 2009

The IPCC, however, takes a broader view of energy sector emissions by assessing the total greenhouse gas emissions contributed by various sources of electricity generation over the life cycle of the technology. Thus, for example, a concrete hydro-electric dam includes emissions incurred during the extraction, transport and conversion of materials (such as cement) used in its construction, as well as in its operation. The resulting table (figure 16) shows that coal-fired electricity generation is orders of magnitude more harmful than, say, solar, wind or hydro power as far as greenhouse gas emissions are concerned.

Figure 16. Median carbon dioxide emissions by source of electricity generation: lifecycle CO₂ equivalent per kilowatt-hour (gCO₂eq/kWh)

Source <i>(Existing commercial)</i>	Median emissions (gCO₂eq/kWh)
Pulverised coal	820
Biomass, co-firing with coal	740
Combined cycle gas	490
Dedicated biomass	230
Solar photo-voltaic: utility scale	48
Solar photo-voltaic: rooftop	41
Geothermal	38
Concentrated solar	27
Hydro	24
Offshore wind	12
Nuclear	12
Onshore wind	11
<i>(Pre-commercial)</i>	
Carbon capture and storage – pulverised coal	220
Carbon capture and storage – coal – integrated gasifier combined cycle	200
Carbon capture and storage – gas – combined cycle	170
Carbon capture and storage – coal – oxyfuel	160
Ocean - tidal and wave	17

Source: based on IPCC 2014c, p. 1335

Even ‘pre-commercial’ generation technologies involving fossil fuel carbon capture and storage, though much less polluting than existing coal and gas systems, are far more polluting over their life cycle than all renewable and nuclear technologies. This leads to comparing the monetary and other costs of each form of generation, which are the major determinants of viability. These key relationships are discussed in the chapter 10 case study on nuclear-electric power.

Deforestation

Globally, net deforestation is not quite as bad as might be expected. Generally speaking, deforestation is continuing in developing countries, while reforestation is continuing in developed countries. As a result, tropical forests are in decline whereas temperate forests are actually increasing. As far as tropical forests are concerned, one widely cited World Bank study, based on the results of 140 analyses using economic modelling, indicates ambiguity about how

factors such as population, income and security of tenure affect tropical deforestation. According to the study, economic liberalisation reforms may increase pressure on tropical forests (Angelsen & Kaimowitz 1999). More recently, in the Amazon for example, there is evidence that the rate of tropical deforestation can be reduced using accurate satellite imaging combined with cadastral reform (Chomitz 2015).

However, forests are more than just trees. To the extent that natural forests are replaced with monocultural plantations, there is an inevitable loss of ecosystem and biodiversity. The UN Forum on Forests (UNFF), which aims to promote sustainable forest management and prevent forest degradation was only established as a permanent body at the turn of the millennium (UNFF 2004). As the overall net rate of forest loss appears unclear⁵² and depends on definitional factors such as percentage of crown cover (Lang 2015), it is not possible to claim that the planet's forests are at present sustainable overall, and especially in respect of the biodiversity they embrace.

Risks

By way of summarising the risks now faced, the thirty-year old Brundtland report identified the stand out risks of a high energy future. They are climate change, urban air pollution and acidification of the environment – all produced from the combustion of fossil fuels – as well as the risks of accident, waste disposal and proliferation, all associated with nuclear energy (Brundtland 1987, pp. 121-122).

Another major problem arises from the growing scarcity of fuelwood in developing countries. Brundtland indicated that if trends continued, by the year 2000 around 2.4 billion people would be living in areas where wood is extremely scarce. In fact, a more recent study points to fuelwood dependency in parts of Kenya as well as in other countries such as Bangladesh and Ethiopia at rates of around 95 per cent in rural areas, and that between 84 and 94 percent of people experienced fuelwood shortage. Much of this shortage appears due to agriculture replacing forest land use (Stacey et al 2013, p. 4140), which due to its unsustainability creates a demand for alternative cheap energy in the developing world.

Metrics

Whilst blatant impacts such as the extinction of particular species can be obvious, there is less clarity about the measurement of other impacts, or overall impact for that matter. There are four variables in the IPAT identity. Two of them are fairly clear: 'population' simply means the number of individual humans alive at any one time. 'Affluence' in the equation means the amount of goods and services consumed, on average, by each person in a year. Population is a straightforward measurement, simply a number. Affluence is usually measured by GDP per person as it represents average consumption, and is therefore expressed in monetary units – usually US dollars – per person.

However, a persistent thread over the decades has been how the 'T' in I=PAT has changed. And if the meaning of 'T' has changed, then so must 'I', because the equation says that impact is proportional to technology, as well as to population and affluence. Early on, 'T' meant *pollution*, then *emissions*, then *waste*. It has also meant *damage per unit of production*, or *energy per unit GDP*, or *'the residual of all that impacts the environment that is not A or P'*, or *patents* (as in the Kolbert-Steffen example above), and so on. Because the nature of human

⁵² According to the FAO, the net yearly rate of forest lost was 0.18% in the 1990s, falling to 0.08% between 2010 and 2015. However, this apparent improvement included a change in definition of forest crown cover from 20% to 10% (Lang 2015).

impact on the environment critically depends on the meaning of T in the IPAT equation, an important question is, what is the best metric for T?

An appropriate metric for technology might follow from the notion of impact as 'ecological footprint', or the area of ecosystem required to sustain an existing human population (Wackernagel 1994, Wackernagel & Rees 1996). If the I in I=PAT is impact, then the equation says impact is proportional to T (technology). Footprint is commonly measured in hectares. Recasting I=PAT, we find that $T=I/PA$. Therefore,

$$T = I: (\text{footprint (hectares)}) / P: (\text{population}) \times A: (\text{GDP dollars} / \text{population}).$$

The *populations* cancel out, leaving $T = \text{footprint (hectares)} / \text{GDP (dollars)}$. Thus T is measured in hectares of impact per dollar of consumption. This is an annual flow, given that GDP is income or consumption over one year. The original I=PAT formulation then becomes:

$$I: (\text{footprint (hectares)}) = P: \frac{(\text{population})}{1} \times A: \frac{(\text{GDP (dollars)})}{(\text{population})} \times T: \frac{(\text{footprint (hectares)})}{(\text{GDP (dollars)})},$$

which is self-evidently true, since the populations cancel out as do the GDPs, leaving *footprint (hectares) = footprint (hectares)*.

It is possible to conceive of a technology that is less harmful than another technology. Thus, for the same population and average consumption, T and therefore I would be reduced, or the footprint made smaller. The equation shows that this can be achieved by increasing the cost of the footprint, but only if it reduces without increasing consumption, or GDP. If the cost of the footprint ($T: \frac{(\text{footprint (hectares)})}{(\text{GDP (dollars)})}$), decreases as a result of increased consumption, then that consumption will be cancelled by the same increase in A. Rather, what is required for a smaller footprint (I) is a technology (T) that minimises footprint independent of consumption (A). Technologies that enable more intensive agriculture are examples of this sort. There is also support for such a possibility in the '*environmentalist's paradox*'. Not only is human well-being now increasing as ecosystems are degraded, but technology can be used to enhance ecosystems rather than just replace them or mitigate their damage (Raudsepp-Hearne et al 2010, p. 586).

Alternatively, because we are a *species with energy intensive technology* (SWEIT) that distinguishes us from all other species on this planet, and which importantly has caused much of our present conundrum, technology and therefore impact may be measured in terms of energy intensity. The Earth is essentially a solar-powered life-support system. As well as direct radiation, solar services include weather, photosynthesis (food), fossil fuels and natural waste disposal. The rate of energy usage per person fulfils the metric of energy intensity: it is a property of human society, it is measurable, and there are appropriate units such as kilowatts per person. Following this logic, the dimension of impact (I) is therefore power, or energy per unit time.

Assuming that we are dealing in rates of change rather than accrued stocks, such as the rate of consumption rather than accumulated wealth, a footprint using this metric would measure the fraction of the Earth's life support services consumed per unit time. Because the Earth's life-support services are solar powered, it is reasonable that footprint can be measured in units of solar power, or incoming energy per unit time. A dimensional analysis of the elements of the I=PAT equation is therefore based on: e = energy, t = time, and c = consumption:

I is Impact, with dimensions e/t,
P is population, which is simply a number, and
A is affluence with dimensions c/t/person.

Recasting I=PA results in $T=I/PA$ as before. Therefore, the dimensions of technology (T) are: (energy/time) / (population X ((consumption/time) / person))). The 'times' cancel and so do the 'populations'. Therefore, $T = \text{energy} / \text{consumption}$. This is essentially the affordability of energy. A valid unit would be kilowatt-hours per dollar. The original I=PA formulation then becomes:

$$I (\text{footprint: energy/time, or power}) = P: \frac{(\text{population})}{1} \times A: \frac{(\text{GDP})}{(\text{population})} \times T: \frac{(\text{energy/time})}{(\text{GDP})}$$

Thus the more affordable energy becomes through technology, the greater the impact of a given human population. This makes sense in the real world. For example, where petrol (gasoline) is cheap as in the US, the environmental impact of inefficient 'gas guzzler' cars is greater than in say France, where fuel is more than double US prices and cars are smaller and more efficient, and rail transport is more widely used. Similarly, where electricity is cheap, more is used. There are three main impacts: there are resource impacts for the stored energies used, there are pollution impacts due to the energy conversions involved and there are direct impacts on habitat resulting from processes and machinery using the energy that technologies make available.

And yet...there is still another way of looking through the IPAT lens. Cheap energy is not necessarily destructive of the environment. It depends on both its source and how it is used. If it pollutes and it is used for the destruction of habitat, then impact is greater. But if its source is non-polluting and it is used to minimise impact through closed systems, then it can benefit both humanity and the biosphere.

Minimising

A different approach – that of factors – shows promise in policy terms, and does relate to resource productivity (Chertow 2000, p. 24). The Factor 10 Club wants to reduce resource use to the extent that resource productivity must increase by a factor of ten over the 30-50 years from the mid 1990s, based on better technologies and methods.

Vaclav Smil in *Harvesting the Biosphere: What We Have Taken from Nature* writes of the "metabolic imperatives" that still drive us and which have already transformed the planet. The harvesting of plants for food remains "the quintessential activity of modern civilisation" (Smil 2013, p. viii). He later summarises the conditions necessary to "minimise human claims on the biosphere's productivity", remarking that this is not difficult to do.

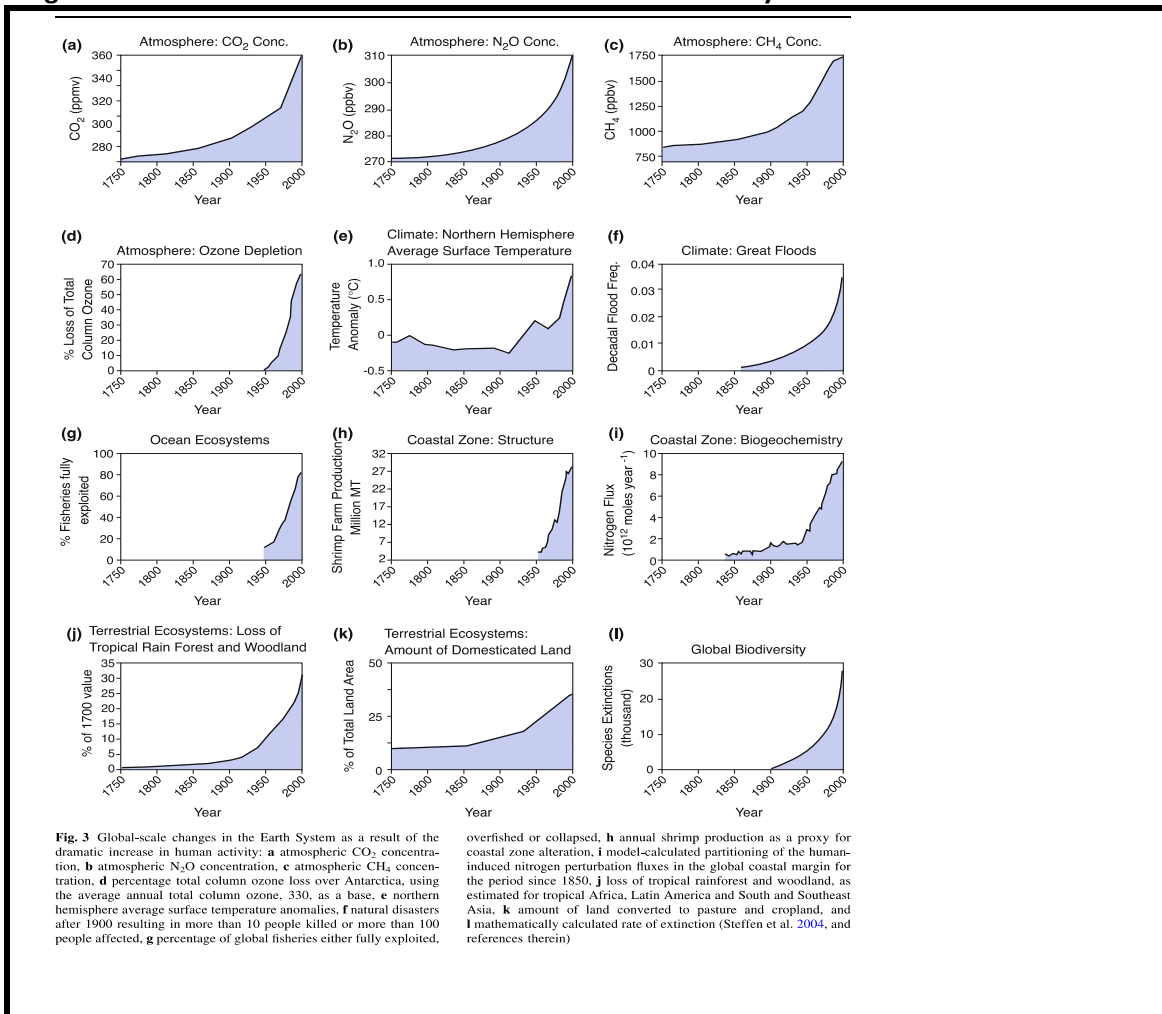
First on his list is stabilising the world population at less than nine billion. This is then aided by using "best agronomic practices" for food production including crop rotation rather than monoculture, limiting per capita food requirements to healthy levels and through much greater attention to post-harvest food loss and household food waste. Smil says we should develop cereal permacultures, and grain staples that can fix nitrogen. Timber harvesting should be limited to the long-term capacities of forest ecosystems and its demand restricted by banning disposable packaging. As well as demand reduction through different technologies, more productive types of trees should be developed:

the greatest savings of woody phytomass could result from a universal adoption of efficient rural wood stoves, such as those that have been widely diffused in China (Smil 2004); by whole tree utilisation and expanded production of engineered timber (Williamson 2001); by even higher rates of paper recycling (McKinney 1994); and by further shift from paper-based records to purely electronic files. Looking further ahead, expansion of crop and wood harvests may not require conversion of substantially larger undisturbed areas to cropping or to wood plantations thanks to new high-yielding transgenic plants (Ibid, p. 630).

Indicators and boundaries

In order to provide a clearer view of human impact from the beginning of the Industrial Revolution, a series of global scale indicators has been developed. Figure 17 below shows 12 indicators, of which four concern atmospheric gas concentrations, two are climate effects, three concern ocean and coastal ecosystems, two are about land use and the final one is biodiversity, measured by extinctions. Some, such as (h) “shrimp production as a proxy for coastal zone alteration” may be questioned, but certainly shrimp farming, which accounts for almost all the shrimp production increase since 1950, does significantly affect low-lying coastal zones (Hernández-Cornejo & Ruiz-Luna 2000) and must be proportionate to production volumes. Nevertheless, the shape of each graphs is reasonably consistent and indicates strong tendencies to unsustainable impacts against all of the indicators.

Figure 17. Global environmental indicators of unsustainability



Source: Steffen et al 2011

What these indicators in figure 17 do not show, however, is how close to unsustainable limits the Earth is at already. The concept of planetary boundaries – impact limits on key features of the earth system beyond which sustainability is jeopardised – was proposed fairly recently. Steffen, Rockström & Costanza (2011) argue for boundaries in ten major “Earth-system processes” as outlined in figure 18 below.

While there is some loss of clarity due to the metrics used (lower numbers generally represent greater sustainability, but represent less sustainability for both ocean acidification and ozone depletion), the concept helps clarify the dynamics of human impact, which earth systems are most affected, and where limits have already been exceeded. Notably, it is far broader than the issue of climate change.

Figure 18. Proposed planetary boundaries

Earth-System Process	Parameters	Proposed Boundary	Current Status	Pre-industrial Value
Climate Change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per meter squared)	1	1.5	0
Rate of Biodiversity Loss	Extinction Rate (number of species per million species per year)	10	>100	0.1-1
Nitrogen Cycle (part of a boundary with the phosphorus cycle)	Amount of N ₂ removed from the atmosphere for human use (million of tonnes per year)	35	121	0
Phosphorus Cycle (part of a boundary with the nitrogen cycle)	Quality of P flowing into the oceans (million of tonnes per year)	11	8.5-9.5	-1
Stratospheric Ozone Depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean Acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global Freshwater Use	Consumption of freshwater by humans (km ³ per year)	4,000	2,600	415
Change in Land Use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	To be determined		
Chemical Pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disruptors, heavy metals, and nuclear waste in, the global environment or the effects on the ecosystem and functioning of Earth system thereof	To be determined		

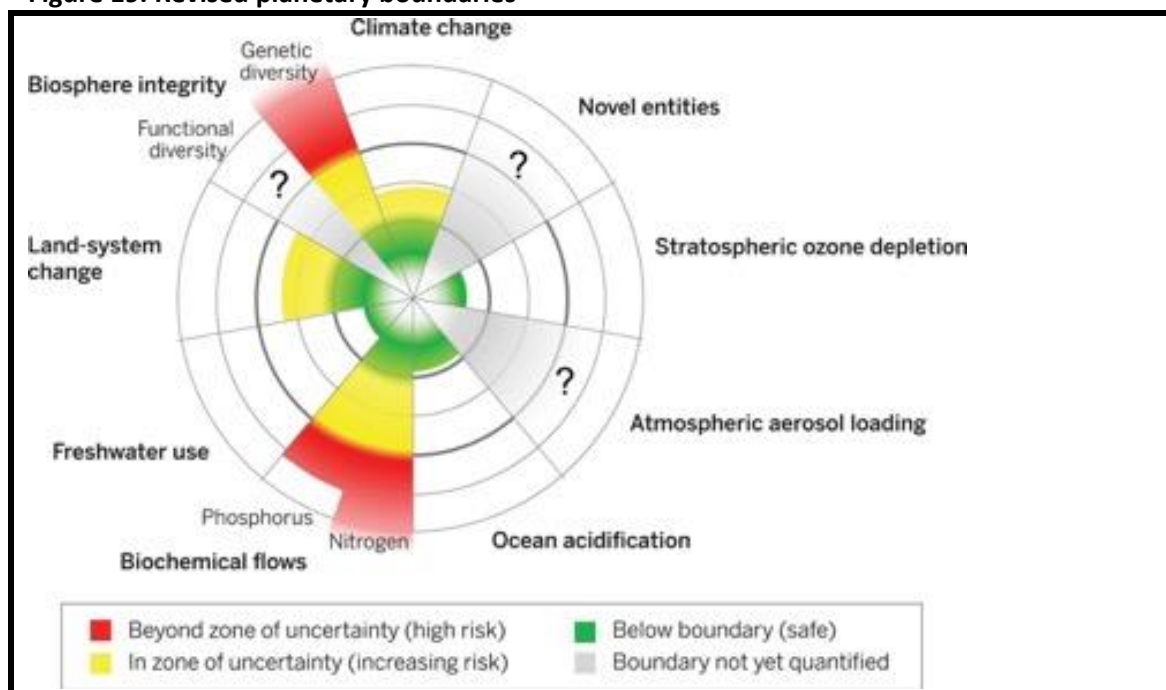
Source: Steffen, Rockström & Costanza 2011

The boundary approach helps focus assessment and policy on some of the most important aspects of sustainability. Intriguingly, however, the authors return obliquely to the IPAT identity in their final comments:

the planetary boundaries approach doesn't say anything explicit about resource use, affluence, or human population size. These are part of the trade-offs that allow humanity to continue to pursue increased well-being. The boundaries simply define the regions of global environment space that, if human activities push the Earth system into that space, would lead to unacceptably deleterious consequences for humanity as a whole...Because the planetary boundaries approach says nothing about the distribution of affluence and technologies among the human population, a "fortress world," in which there are huge differences in the distribution of wealth, and a much more egalitarian world, with more equitable socioeconomic systems, could equally well satisfy the boundary conditions. These two socioeconomic states, however, would deliver vastly different outcomes for human well-being. Thus, remaining within the planetary boundaries is a necessary—but not sufficient—condition for a bright future for humanity (Steffen, Rockström & Costanza 2011, paras 23-24).

A revised assessment (figure 19 below) shows that at least three earth systems processes, *genetic diversity* (formerly 'rate of biodiversity loss'), and the phosphorous and nitrogen cycles' in *biochemical flows*⁵³ are already well beyond safe operating space at high risk of abrupt change. Three more are of uncertain but increasing risk: *novel entities* (formerly 'chemical pollution'), *atmospheric aerosol loading* and *functional diversity*, part of *biosphere integrity*. Only freshwater use, ocean acidification and ozone depletion are yet at relatively safe levels (Steffen et al 2015).

Figure 19. Revised planetary boundaries



Source: Steffen et al 2015

⁵³ There appears to be a misprint in the diagram. 'Biochemical flows' is referred to as 'biogeochemical flows' in the text.

It is nevertheless implied in all of this that human impact upon the biosphere is unevenly distributed. Particulate emissions from factories, power stations and arterial roads is concentrated in and around cities. Compound contamination such as from heavy metals most affects rivers and especially estuarine bays. The Grand Banks remain devoid of cod, while in Icelandic waters cod still thrive. Animals and vegetation adapted for high altitudes and low temperatures have nowhere to go as glaciers melt; their low-altitude cousins may still move to higher ground. Continents allow for some migration; islands become hunting grounds from which there is no escape. Coastal mangroves are destroyed; rocky cliffs remain. The people of Kiribati prepare for inundation; the Sudanese, Ethiopians and Kenyans see desert encroaching.

Conclusion

Human impact on the biosphere is already unsustainable in relation to several earth systems, including the rapid decline of many species. Much impact results from the use of cheap energy. We are the only species on the planet that artificially harnesses intensive energy and compared with similar species, human impact on this planet is orders of magnitude greater than any other. Compared with other SWEITs that may have existed or yet exist within the galaxy the plight we face may not be unique, but the continuation of our civilisation is precarious and clearly interwoven with our energy practice.

The impact of humans in the world is excessive and rapidly getting worse

– Arne Naess and Stephen Harding, cited in Higgins 2013.

Chapter 4. Population

There is only one man too many on Earth, and that is Mr. Malthus – Pierre-Joseph Proudhon

Leaving rural France and arriving in Hong Kong for a rugby match, I wondered if I were in the future. Under an angry soot-stained sky in this swarming city, the buildings like close-packed daggers thrust around the harbour, there was graffiti in a dark alley. *As density grows, so does our loneliness*, it said in block-lettered English. In the crowded streets it felt true. Faces were the inscrutable of cliché, often weary-looking, and each apparently alone with their thoughts. But do people packed together equal loneliness any more than life with less human mass? And why in English in a Cantonese city? Is it that language is a source of isolation where density is greatest because difference becomes more obvious? Before the Industrial Revolution, the divergent dialects of separate rural groups mattered little because they seldom met. But isolation is made apparent when one cannot understand the language of a neighbour who may live only a thin wall alongside one's apartment.

This chapter evaluates the relationship of population to sustainability, how population policy has evolved over time and space, and how it may apply to a present and future world. It argues that while the rate of population change is critical, and non-coercive measures such as migration, education and contraception are more effective in checking growth in our numbers, a viable population policy will result in increasing density this century such is the result of momentum.

Half a century ago the 'population explosion' had the same central role in public discourse that 'global warming' does now (Friedman 2013, para. 19). The Erlichs' 1968 *Population Bomb* was a runaway best seller. Population then was considered the central factor leading to poverty, unsustainability and catastrophe⁵⁴. Policies designed to curb the growth in our numbers were applied over much of the developing world – by China with its one-child policy, by India with its sterilisation program and by the US as part of its foreign aid agenda.

Friedman's brief contemporary calculation of population density designed to test the belief that overpopulation caused poverty had a counter-intuitive result: the five most densely populated countries were all relatively affluent. They were Belgium and the Netherlands, both already rich and developed as well as the rapidly developing 'Asian tigers' of Taiwan, South Korea and Singapore. If Hong Kong were an independent country it would have been included as it had about ten times the population density of Singapore (Ibid, para. 20).

Limits

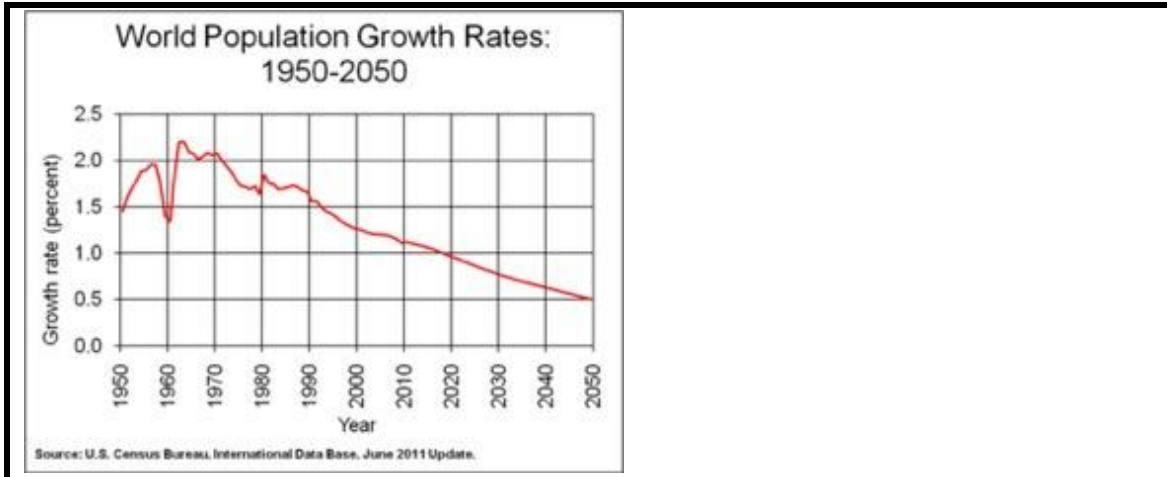
As far as the wider impact of population is concerned, including poverty, this particular variable has a long history of contemplation and warning of dire consequence, beginning more than two millennia earlier and especially including the views of Adam Smith, Thomas Malthus and David Ricardo in the late eighteenth and early nineteenth centuries.

Not all are doomsayers, though. For example, one of the original authors of the chilling *The Limits to Growth* (Meadows et al, 1972), Jørgen Randers (2013), since concluded, based on demographic trends caused primarily by urbanisation and the availability of contraception, that the human world population will peak at less than nine billion by 2040 and then begin to

⁵⁴ According to *The Population Bomb*, "In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now" (Erlich 1968, p. xi).

decline. Europe, Japan, Russia and China have already begun to do so. Africa has already reduced its fertility rate from seven to five per woman during the past fifty years. UK science author, Fred Pearce agrees, having written about the 'coming population crash', and particularly links the rise of feminism and education as factors in declining birth rates (Pearce 2010, Eby 2010). Randers further advocates that it is both desirable and possible to reduce the human population to around four billion by 2100 given a focused global public policy. The central factor in this optimism is that while population still continues to grow, the rate of increase is slowing and may arrive at below the rate need just to maintain our numbers, as figure 20 below illustrates:

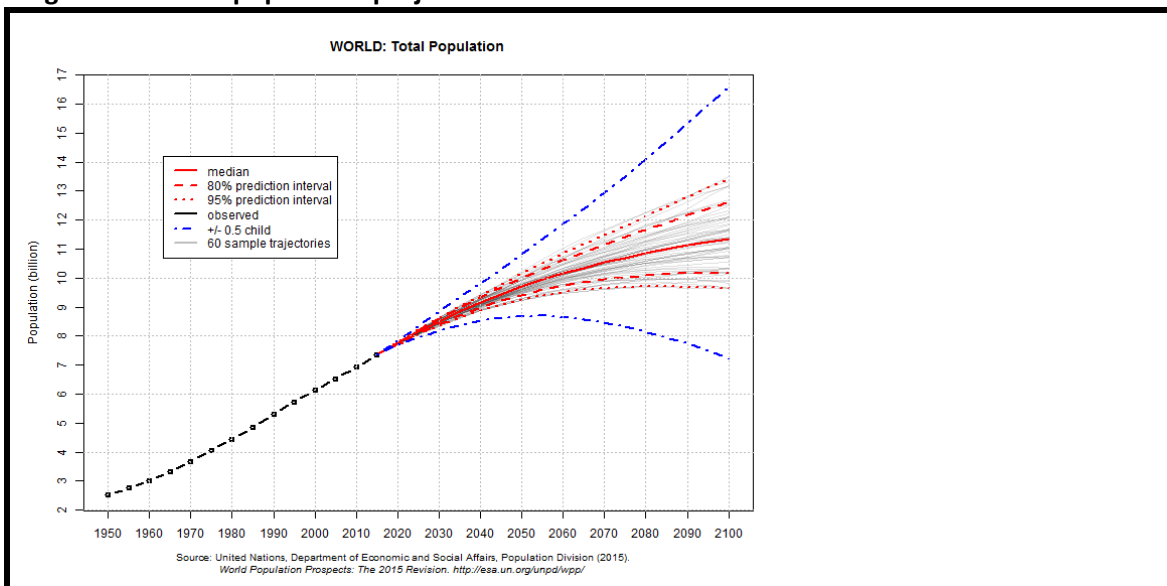
Figure 20. World population growth rates 1950-2050



Source: US Census Bureau 2011

A zero population growth rate after 2050 does appear possible, but the achievement of any significant population reduction after that time seems unlikely. Since Randers' population control optimism, more recent UN estimates project that there could be more than eleven billion of us by the end of this century (figure 21 below). Despite the observed decline in fertility rates, much of the increase will be from Africa (McKenna 2017), such is the momentum from earlier and current increases in our numbers:

Figure 21. World population projections to 2100



Source: UNDESA, Population Division 2015

Making accurate predictions of total human population over the long-term is particularly difficult because of the cumulative effect of variables affecting birth and death rates. For those specialised in disciplines other than demography, it would seem especially so. For example, the Cambridge astronomer, Fred Hoyle, in a 1964 discussion on the desirability of populating the galaxy, indicated that “some 10^{10} humans...will be on Earth by the year A.D. 2000” (Hoyle, 1964, p. 42), or ten billion people rather than the little more than six billion it actually was at the end of the millennium. The difference of nearly four billion people between his prediction and reality is remarkable. It may have been due to his discipline as an astronomer which, as mentioned above under *Impact*, is reputedly unconcerned by imprecision. It may have been due to the widespread concerns of the population alarmists at the time; or perhaps simply due to a flawed assumption that the very high population growth rate at the time (see figure 20) would continue.

Fears

Fears of both over and under-population have in the past gained sway over relatively short periods of time. In writing about the connections between early capitalism and slavery, Eric Williams (1944 p. 16) observes that in relation to Britain, “fear of overpopulation at the beginning of the seventeenth century gave way to a fear of underpopulation in the middle of the same century”.

This fear was based on the mercantilist economic argument that in order to compete with other countries it was best to reduce costs by paying low wages. And the way to ensure low wages was to have a large population. The mercantilist economist and later governor of the British East India Company, Sir Josiah Child, in commenting on the colonisation of America as an exception, still advanced the then majority opinion that “whatever tends to the depopulating of a kingdom tends to the impoverishment of it” (Child 1751 [1668], p. 134) and further:

Most nations in the civilised parts of the world, are more or less rich or poor, proportionally to the plenty or paucity of their people, and not to the sterility or fruitfulness of their lands (Ibid).

While this argument – that greater wealth arises from cheap labour – contains obvious contradiction,⁵⁵ it retained popular currency in that time. A century later, however, Adam Smith disagreed. Writing at about the period of the American Revolution and the beginnings of industrialisation, he drew attention to populous China and the impoverishment of its citizens. He referred to China as an example of an advanced nation that had changed little since the time of Marco Polo, where its economic stagnation produced a general poverty that “far surpasses that of the most beggarly nations of Europe” (Smith 1952 [1776], pp. 31-32). Having noticed that every species multiplies according to its means of subsistence and not beyond it, Smith favoured economic growth rather than absolute numbers of people as the path to national wealth, a view that again holds sway, so far, in the current century.

Malthus

At the edge of the nineteenth century and a generation after Smith, the cleric and Cambridge political economist, Thomas Malthus (1766-1834), himself one of eight children, found popularity, influence and controversy with his best-seller, *Essay on the Principle of Population* (1798) that went through six editions. This is the work to which much of the modern concern

⁵⁵ The contradiction is that the wealth must not accrue to the labourers, who would otherwise not be cheap.

about overpopulation can be traced. The essence of his 'principle' is that food supply limits population growth because it can only increase arithmetically, whereas population can increase geometrically. Thus Malthus linked overpopulation to poverty, encouraging harsh measures aimed at making the poor more 'responsible' and less likely to reproduce themselves. In fact, Malthus' views were developed as another Victorian 'iron law', which implied that poverty, war, abstinence and birth control were needed to hold the population in check lest food supplies ran out.

Malthus' views were provocative to say the least. In the second edition of his Essay, he included the following before it was removed in later editions due to the antagonism it created:

"A man who is born into a world already possessed, if he cannot get subsistence from his parents on whom he has a just demand, and if the society do not want his labour, has no claim of right to the smallest portion of food, and, in fact, has no business to be where he is. At nature's mighty feast there is no vacant cover for him. She tells him to be gone, and will quickly execute her own orders, if he does not work upon the compassion of some of her guests. If these guests get up and make room for him, other intruders immediately appear demanding the same favour (Malthus 1803, p. 531).

According to Garrett Hardin (1998, p. 182), pointedly writing during the bicentennial of Malthus' essay, while those words almost guaranteed controversy, they also "walked right past the central problem of population" – the denial of "limits in the supply of terrestrial resources".

In a Malthusian spirit, the UK poor law was amended in 1834 to preclude any public money or assistance to the able-bodied. Malthus' friend, David Ricardo (1772-1823), had urged such a measure, writing in 1817 that it was in the best interests of the poor:

It is a truth which admits not a doubt that the comforts and well-being of the poor cannot be permanently secured without some regard on their part, or some effort on the part of the legislature, to regulate the increase of their numbers, and to render less frequent among them early and improvident marriages. The operation of the system of poor laws⁵⁶ has been directly contrary to this. They have rendered restraint superfluous, and have invited imprudence, by offering it a portion of the wages of prudence and industry (Ricardo 1911 [1817], p. 61).

But while Ricardo and Victorian biologists such as Wallace and Darwin were impressed by Malthusian ideas in relation to the "survival of the fittest", other political economists were appalled. Socialists and Marxists of the era especially tended to believe that poverty was rather a result of maldistribution or economic inequality, reputedly leading the French anarcho-socialist Pierre-Joseph Proudhon (1809-1865) to declare his loathing of Malthus as per the quotation that begins this chapter.

In direct refutation of Malthus, Friedrich Engels, for example, wrote the following tirade:

⁵⁶ Polanyi (2001 [1944]), details the *Speenhamland* decision of 1795 in England, which in effect guaranteed to labourers a minimum income based on the price of bread irrespective of their effort and production.

Malthus...maintains that population is always pressing on the means of subsistence; that as soon as production increases, population increases in the same proportion; and that the inherent tendency of the population to multiply in excess of the available means of subsistence is the root of all misery and all vice. For, when there are too many people, they have to be disposed of in one way or another: either they must be killed by violence or they must starve...The implications of this line of thought are that since it is precisely the poor who are the surplus, nothing should be done for them except to make their dying of starvation as easy as possible, and to convince them that it cannot be helped and that there is no other salvation for their whole class than keeping propagation down to the absolute minimum. Or if this proves impossible, then it is after all better to establish a state institution for the painless killing of the children of the poor...Charity is to be considered a crime, since it supports the augmentation of the surplus population. Indeed, it will be very advantageous to declare poverty a crime and to turn poor-houses into prisons, as has already happened in England as a result of the new "liberal" Poor Law (Engels 1844, para. 53).

Engels was unconcerned about human population pressure because:

The productive power at mankind's disposal is immeasurable. The productivity of the soil can be increased ad infinitum by the application of capital, labour and science...day by day science increasingly makes the forces of nature subject to man (Ibid, para 51).

Others were not so sure. The American economist, more a "curiosity" than influential, Henry Carey (1793-1879), although optimistic about the widespread benefits of progress and economic growth, was nevertheless "more than half agreed with Malthus" on the procreative power of humanity (Galbraith 1976 [1958], p. 40). Carey wrote that the time may come "when there will not even be standing room" (quoted in Gray, 1931, p. 256). At least, despite the power of compound increase, we are not yet at that point.

A corollary to Malthus written by Ricardo further demonstrates the interplay between population, affluence and technology. Ricardo contended that the level of income at which the Malthusian population would be stable depended on the tastes of the poor. In a remarkable insight, he argued that the more luxurious the tastes of the masses, the more likely population would stabilise, as the relative cost of an additional child was an incentive to hold down the birth rate. Hence he concluded that the "friends of mankind" should wish that the workers have more luxurious tastes (cited in Friedman 2013, para 15). Before the industrial revolution, less attractive "friends of mankind" held the population in check and living standards relatively stable. These included the scourges of "war, violence, disorder, harvest failure, collapsed infrastructures, [and] bad sanitation" (Clark 2007, p. 5).

It was only after 1800 in the West that population growth escaped from its long flat trajectory – before held back by such scourges, especially the food supply. With accelerating production technologies, including in agriculture, affluence increased and human population began to exceed its Smith-Malthusian boundaries.

In the East, Japan now leads an apparent transition to a much lower population. Its numbers peaked at about 128 million in 2008 and is in subsequent rapid decline, currently losing about 250,000 a year and the rate of loss is increasing:

...the Japanese population gradually grew from the beginning of the Meiji period, increased by 70 million in the 140 years up to 2008, and is about to decrease by 70 million in the 90 years leading up to the year 2100 (Masuda 2015, para 8).

This means that the Japanese population is now decreasing faster than its earlier explosive growth during the twentieth century. Even if Japan does increase its birthrate significantly in line with national targets, its population will not increase because there are now too few women of child-bearing age. Geographically, the effect of population decline is evident in the concentration of people in Tokyo and the depopulation of the countryside, such that Tokyo's numbers will not begin to decline until after 2020, whereas half of all municipalities have faced severe population loss since 2010 (Ibid, paras 5-6). While especially foreign commentators point to the obvious measure of increasing immigration to slow population loss (Panda 2014) the Japanese cultural attitude to blood purity and unique identity⁵⁷ prevents any implementation. Tokyo University's Hiroya Masuda, for example, fails to even mention it in his public policy lecture quoted above. Ninety-eight per cent of its population are ethnically Japanese. As population shrinks, the proportion of older – and more culturally conservative – people grows, making policy change increasingly difficult politically. At the same time the concentration of the population in Tokyo further depresses fertility – lengthy commute times, high expenses and extended work and study hours in the big city are not conducive to breeding.

However, especially if Japan is a miners' canary for population, it is the *rate* of decrease that is of policy concern rather than where Japan's numbers ultimately stabilise. Some very small countries (Norway, Sweden, Switzerland) seem to cope well on the human development index (HDI). Absolute population is largely irrelevant to economic success. But a teetering, runaway population plunge distorts the demographics and, at least over two or three generations, leads to a rapidly ageing nation. In Japan, the void of young people is being filled with robots.

Optimism

In a spirit of technological optimism similar to Engels, but with more respect for nature than to simply require its subjugation, writing a hundred and thirty years later Arthur Clarke foresaw a transformed future. This was a twenty-third century world, in which the "endless forests of the American Midwest...so much the Earth must have looked in ancient days" and which were recently all farmland, are restored. Consequently, wolves, buffalo and the grizzly bear roam free from the threat of humankind (Clarke 1975, p. 116). The twenty-first century return of much New England farmland to the wild and the recent re-introduction of wolves into the world's first national park, Yellowstone, indicates this concept is feasible. This 'rewilding' has in a short time cascaded⁵⁸ positive environmental effects including the return of several species and even the change of the course of rivers (Monbiot 2014b). But Clarke's future Earth is based on a much reduced population of only a few hundred million, albeit with additional human colonies established on the moons of Saturn.

Randers had earlier predicted environmental, resource and human catastrophe this century due to the exponential growth of our species and its impacts. Early computer modelling helped explain its scenarios. However, the US-based libertarian Foundation for Economic Education believes that the risks of overpopulation are overstated. In *Overpopulation: The Perennial Myth* US libertarian David Osterfeld (1993, para. 22) writes that "the prospect of the Malthusian nightmare is growing steadily more remote." In support he quotes the second

⁵⁷ *Nihonjinron* (日本人論) is a concept of Japanese national and cultural identity, based on ideas of the Japanese race as unique in an isolated archipelago with a unique climate and way of thinking.

⁵⁸ That is from a top predator down to other species, to flora and to landforms.

century Carthaginian, Tertullian (160-c.220 AD), a Christian priest who lived when the world population was around 190 million:

Our numbers are burdensome to the world, which can hardly support us...In very deed, pestilence, and famine, and wars, and earthquakes have to be regarded as a remedy for nations, as the means of pruning the luxuriance of the human race (quoted in Osterfeld 1993, para. 1).

During the 1960s and despite the predominance of Erlich's *Population Bomb*, Buckminster Fuller was typically optimistic about population growth:

The population explosion is a myth. As we industrialise, down goes the annual birth rate. If we survive, by 1985, the whole world will be industrialised, and, as with the United States, and as with all Europe and Russia and Japan today, the birth rate will be dwindling and the bulge in population will be recognised as accounted for exclusively by those who are living longer (Buckminster Fuller 1969, p. 43).

Other than Tertullian, early concerns were expressed about overpopulation by, for example, Confucius in the sixth century B.C., Plato and Aristotle in the fourth century B.C., as well as by the sixteenth century Italian, Botero. And today, Malthus' shadow still looms over contemporary science. An article, 'The Millennium Assessment', in *BioScience* (Powledge 2007a) that relates the increasing pressures on ecosystems attracted this criticism in the next issue:

What I find lacking in the whole approach, not only in this article but in the profession as a whole, is the failure to openly recognise that none of it matters as long as we fail to correct the underlying cause of nearly all of our problems: overpopulation (Bennett 2007, p. 101).

In his response, the article's author points out that in fact there was reference to overpopulation as a fundamental cause: "increasing consumption per person, multiplied by a growing human population, are the root causes of the increasing demand for ecosystem services" (Ibid, p. 4). However, he laments that what's missing from most such discussions is a plan for dealing with overpopulation that the world will accept. "That's a terribly difficult cat to bell" (Powledge 2007b, p. 101).

Lebensraum

Population is one thing. Space to accommodate it is another. Alison Bashford, in an article on Karl Haushofer's geopolitics of the Pacific, draws attention to the notion of *Lebensraum*, infamously associated with Nazi policy in the second quarter of the twentieth century. The concept was promoted by Haushofer (1869-1946) through his writings around the turn of the century. The link with Nazism is quite direct: Haushofer visited his assistant and former student, Rudolf Hess, in a Munich prison in 1924. He also visited a friend of Hess in the same prison, one Adolf Hitler, who was then writing *Mein Kampf*, and confined as he was personally, may well have felt a particular attraction to the concept of 'living room'. Certainly the loss of the German Pacific colonies⁵⁹ after the Great War was used as a partial justification for Germany's quest for eastern expansion during the Nazi era (Bashford 2012, p. 121).

⁵⁹ The German Pacific colonies comprised New Guinea, including the Northern Solomons, Nauru, the Marshall Islands, the Marianas, the Carolines (now the Federated States of Micronesia), Palau and Samoa.

The concept is also associated with the ideas of Malthus and Darwin both. The German zoologist-anthropologist-geographer, Friedrich Ratzel (1844-1904), coined the term “Lebensraum” in the late nineteenth century (Smith 1980, p. 52). Ratzel was influenced in turn by the biologist Ernst Haeckel (1834-1919), who had earlier coined the term “ecology”.⁶⁰ Both were familiar with Malthus and Darwin and were especially interested in the concept of life forms competing within a confined habitat. Ratzel observed that it was no accident that Malthus’ essay on population derived from an island nation, where population pressures were often more apparent. Confined countries could either (positively) expand through emigration or colonisation, or lacking new territory, (negatively) put a low value on human life while remaining within the same boundaries. By this logic, the UK (as well as France and Germany) sought virtuous outlet through colony and empire. Japan, another populous island nation, sought Lebensraum in Manchuria and Micronesia.⁶¹ But in this latter respect, where there was no accessible new territory, Pacific islanders had been observed to practise ways of limiting population growth – cannibalism, sacrifice, infanticide and gender segregation on different islands, amongst others (Bashford 2012, pp. 132-133).

Haushofer was closely associated with this sort of thinking and spent several years in Japan working with the military before the Great War (Ibid, p. 121). Interestingly, Haushofer saw Australia as an antipodean Germany. Not only hemispherically opposite, but also in the sense of an island continent of few people rather than a confined nation of many (Ibid, p. 134). He also saw Australia as a country that, with California, had jointly implemented the Pacific “colour line” where Asian immigration was forbidden as a result of experience with the overly industrious Chinese diaspora during the mid-nineteenth century gold rushes. And at the 1919 Paris Peace Conference Australia had helped resist Japan’s attempt to propose a clause about racial equality in immigration (Ibid, p. 132). As an aside on population representation, when at the peace conference US President Wilson queried Australia’s right to annex former German colonies in the Pacific on the basis that its five millions were opposing the wishes of twelve hundred millions, Prime Minister Billy Hughes retorted that he represented not five million living but rather 60,000 dead – those sacrificed during the war (DVA 2015).

The gleam of Lebensraum lingered on well beyond Haushofer and the fascist dreams, however. Osterfeld in his 1993 article on the ‘myth of overpopulation’ mentioned above, contains a paragraph intriguingly sub-headed ‘*Living space*’:

But even if food and resources are becoming more abundant, certainly this can’t be true for living space. After all, the world is a finite place and the more people in it, the less space there is for everyone. In a statistical sense this is true, of course. But it is also irrelevant. For example, if the entire population of the world were placed in the state of Alaska, every individual would receive nearly 3,500 square feet of space, or about one-half the size of the average American family homestead with front and back yards. Alaska is a big state, but it is a mere one percent of the Earth’s land mass. Less than one-half of one percent of the world’s ice-free land area is used for human settlements (Osterfeld 1993, para. 18).

Despite this sceptical view pointing out that the entire human population could comfortably fit into Alaska (or New Zealand for that matter), the population issue is not so much about

⁶⁰ Coined around 1870, as *Ökologie* in German. It appeared in English in 1873, according to Lynn White (1967, p. 1204).

⁶¹ Japan controlled the Carolinas, the Marianas, the Marshall Islands and Palau from 1914 until 1945. Once Spanish, then German colonies before Japanese, the islands are now de facto US possessions resulting from the Second World War.

space for individuals, and it is disingenuous to imply that it is. It is about space for one species alongside habitable space for all other life forms at the same time. To argue otherwise denies the more threatening issue of sustainability.

This mix of population policy, migration, racism and geo-politics illustrates how complex the issue of population is. While there is still much resettlement due to war and poverty, now in a different era, there is no more *Lebensraum*. The idea of nationalist expansion driven by population pressures, whether contiguous to a country's borders or in distant colonies, seems ridiculous. Short of an unlikely *Battlestar Galactica* forced migration through space, or an "impossible journey" to a distant exoplanet (Kerins 2017), there just is no more room, any more political will, or any more need. The planet is obviously limited, not limitless. Instead, larger human populations must now be dealt with, not by Polynesian techniques, but by increasing densities – through migration and urbanisation.

Urbanisation

The world passed a milestone in 2008. For the first time in human history, more people now live in cities and towns than in rural areas. And while urbanisation has "increased tenfold in the past century" (Crutzen & Stoermer 2000, p. 17), the rate is still accelerating. So-called 'migrant workers' from rural western China still flood the industrialised east and have done so especially since Deng Xiaoping's market-based economic reforms of the late twentieth century. The productivity of agribusiness means that increasingly fewer workers are required in agriculture outside of subsistence. South Africans can have a better existence in Capetown than on the Veld. Formerly rural Tunisians and Senegalese increasingly populate the suburbs of Paris, Marseilles and Lyons.

According to the UN, the proportion of urbanised people is more than 54 per cent (UNESA 2014, p. 2). And contrary to popular perception, cities are often associated with environmental benefit: it is easier to provide environmental services where people are more concentrated and urban populations are more demanding of them, as the Beijing administration is now acutely aware and as London and Pittsburg were a few generations ago in relation to air pollution. Cities strive to provide clean water, sewage treatment facilities and coordinated waste disposal. A concentrated human population not only demands them, but makes such facilities more economically feasible.

However, the megacity centres of Lagos, Mexico City, São Paulo and Dhaka for example, are encircled by slums, in which there are no basic services such as safe drinking water and sanitation, where tenure is insecure, housing lacks durability and there is overcrowding (UN 2014, p. 46). According to the UN, the proportion of the urban population who are slum dwellers in the developing world declined from 47 to 37 per cent between 1990 and 2005, an apparently dramatic and welcomed improvement. But unfortunately, closer inspection of the *Millennium Development Goals report* shows that this apparent advance was mainly due to a change of definition:

The decrease in the percentage of populations living in slum conditions is due in large part to a change in the definition of adequate sanitation. In 2005, only a proportion of households using pit latrines were considered slum households, whereas in 1990 and 2001 all households using pit latrines were counted as slum households. The change affects estimates mostly in those countries where the use of pit latrines is more widespread, as in Sub-Saharan Africa (UN 2007, p. 26).

However, within a further seven years there appeared to be a more genuine improvement with less than 33 per cent of the urban population who were slum dwellers in the developing world. Such was the increasing rate of urbanisation combined with a growing population in the developing world, however, that this represents more people in absolute numbers than in 1990 – 863 million in 2012, compared with 650 million in 1990 (UN 2014a, p. 46). However according to the same UN report, there is new hope in technology: one partial answer to slum improvement is to increase the typically minimal amount of urban land allocated to streets. More and wider streets means that service arteries can be extended more easily. Mapping and planning slum upgrades can be facilitated by geospatial information systems including satellite imaging. As a result of this sort of approach it is known that Dar Es Salaam allocates only four per cent land to streets outside its city centre. The ideal is about 25 per cent (Ibid, p. 47).

But while increasing concentrations of human beings in urban environments, slums or not, is continuing, what does this mean for sustainability? Certainly it appears that there are economic benefits, and possibly there are further advantages. According to former cosmologist and now New York University growth economist, Paul Romer, “policy-induced changes in the urban share of the population could have big effects on GDP per capita and...the quality of life for billions of people” (Romer 2015). If both higher incomes and quality of life are linked with sustainability in the sense of the theoretical environmental Kuznets curve (EKC) that says environmental impact eventually reduces with affluence, then sustainability benefits may be real. Although as discussed in more detail in the section on affluence, waste and carbon emissions are exceptions to this principle, urbanisation and sustainability are partners. People living closely together facilitate the sharing of ideas, which can contribute to both economic and environmental improvement. Higher population densities in cities implies lower birthrates and less population pressure on rural land. And it is surprising how much of the territory of Hong Kong is uninhabited.⁶²

Migration

Migration affects population. Globally of course migration makes absolutely no difference to the number of people on the planet at any one time. However, it does make a difference *over* time. This is because people tend to migrate from poorer to richer areas, whether attracted by better standards of living, or displaced by poverty, conflict or disaster. The continuing urban drift within countries is also part of this, typified by the millions of migrant workers from rural western China lured to the industrialised East in recent decades.

Between countries there is net migration from the global South to the global North, including from Africa to Europe (especially from former colonies), from South Asia and the Middle East to both Europe and North America, from Latin America to the US and Canada, from the Pacific and the Middle East to Australasia, and from southern-central Africa to South Africa.

However, it is the effect of the host culture and rising affluence that tends to reduce fertility within immigrant groups, as high birth rates are associated with rural poverty, lower birth rates with urban affluence. While it may take generations for this reduction to play out, there are fewer incentives in wealthier circumstance to have large families, and more incentives to produce fewer children. Thus immigrant birth rates tend to match the lower birth rates of the host urban, wealthier culture over time. While longevity tends to increase in wealthier environments due to better hygiene, welfare and medical services, the overall effect is that

⁶² Only 21.1 per cent of Hong Kong’s land area is built-up (Wang & Lau 2002, p. 11.3)

the rate of population growth tends to fall as the reduction in birth rates more than offsets the increased longevity.

On this basis, then, sustainability might be enhanced by migration as ultimately it means relatively fewer people. However, this would only be true if the increased affluence and its associated consumption did not result in proportionately greater environmental impact. The state of much of eastern China does not support this possibility at present, especially with regard to emissions and chemical pollutants that have been widely observed in the international media. However further development along greener lines may yet do so as implied by the EKC.

Elephants

US comedian Doug Stanhope alludes to the “elephant in the room” misperception about overpopulation. In his 2010 monologue *Abortion is Green*, Stanhope says that “the major problem is obviously overpopulation” but that the issue never arises. “Even Al Gore has to be pressed to admit it’s even a problem” he says, but if as Gore says “it’s gonna correct itself by 2050, I guess fucking will go out of style”. Moreover, individual efforts to reduce environmental impact are trivial. Ironically, the “combined uteri” of the environmentally aware in the US “wreak more havoc to the environment than a thousand Dow Chemical Corporation accidents combined” (Stanhope 2010).

In *Sex and Destiny: The politics of human fertility*, Germaine Greer anticipated this last assertion in 1985. For her it is the overconsumption of the West interdependent with the ‘serfdom’ of the East and South that has caused environmental havoc, not the numbers of Indians living in poverty (Greer 1985, pp. 409-412). Her book contains pointed criticism of the Erlich’s trip to India, from which their book *The Population Bomb* was conceived. The Erlich’s middle class American sensibilities were shocked by one experience whereby, in a temperature “well over 100°F” and in a taxi “hopping with fleas”:

The streets seemed alive with people. People eating, people washing, people sleeping. People visiting, arguing and screaming. People thrusting their hands through the taxi window begging. People defecating and urinating. People clinging to buses. People herding animals. People, people, people, people. As we moved slowly through the mob, hand horn squawking, the dust, noise, heat and cooking fires gave the scene a hellish aspect (Erlich 1968, p. 1).

For Greer however, it is normally hot in the tropics, she has never encountered a flea-ridden taxi in India and the area where the Erlichs were taken was probably less populated than Manhattan, just that all the people were at ground level, rather than stacked many stories above. Greer does not know how many people the Earth can support. She says though that “it is quite probable” the world has been overpopulated for some time. Nevertheless, it is clear that it can support far more people at a low calorie (as in her contemporary India) than a high calorie intake (as in the Erlichs’ US).

From a contemporary business perspective, Joon Yun is concerned about a different elephant – depopulation rather than overpopulation. He notes that falling fertility and a future global depopulation means that demand for natural resources “could wane” leading to deflation in commodity prices, land, housing and debt. While “much would depend on whether the central banks would choose to allow low-grade deflation or otherwise continue to target low-grade inflation in the face of declining aggregate demand” Yun (2012) asks “where would yield be found in a depopulating world facing the forces of deflation?” This, he says, is in aged care

and health services — an area in which he has a particular interest as CEO of a company that services such industries.

Both these views nevertheless illustrate the sort of tensions that are inherent in population policy and sustainability. As Stanhope implies, the issue is more of an unspoken concern because it is so difficult to deal with. And as Yun infers, the depopulation that is desirable from a sustainability perspective runs counter to an economic system built on the growth in demand that increasing numbers underpin.

Perspectives

There are therefore different perspectives on the population problem both over time and between disciplines, as well as according to self-interest. However, for this dissertation they tend to resolve into two broad questions: (1) Is overpopulation a critical issue for sustainability? and (2) What should be done about it in public policy terms?

In assessing the first question, it has been observed (Dorling, Crutzen, Purdy, Steffen) that the last 200 years have been the most extraordinary period of human history. In that time human population has increased nearly tenfold and carbon dioxide levels started to rise significantly, both associated with the effects of the Industrial Revolution including the rise of public health measures and the burning of fossil fuels.

Still, it is revealing to undertake some mathematical modelling in relation to the increase in human population. One intriguing question is how many people were on the planet around 10,000 years ago at about the dawn of agriculture, when our species first began to break from the immediate growth limits of the environment. If we start with an approximation of the current world population (7 billion people) and assuming a net increase of 0.1 per cent per year on average, then there were 319,000 people on the planet at that time⁶³.

But assuming an average growth rate of 0.2 per cent per year, there would have been *no-one* on the planet then, and there would have been only 17 people on the planet 1000 years ago. Therefore, the former average growth rate of 0.1 per cent is clearly more accurate. The current world population growth rate is now far greater – around 1.4 per cent per year and estimated to decline to around 0.5 per cent by 2050 (Worldometers 2014). Looking 200 years into the future, a growth rate of only the long-term average of 0.1 per cent would result in a definitely unsustainable 51 billion people on the planet! Hence it is important, or rather critical, that zero or negative population growth is effected.

In 1994, Gretchen Daily and the Erlichs concluded that an optimum world population would be between 1.5 and two billion people⁶⁴ to enable both a creative critical mass, as well as to maintain biodiversity: “homo sapiens should foster the continued existence of its only known living companions in the universe” (Daily, Erlich & Erlich 1994). Garrett Hardin (1998, para 3) believes that there is no question about the need for population control. The key issue is how it can be achieved with minimal pain:

The problem is simply this: can the necessity of population control be reconciled with the apparent demands of individualism, as that complex concept has developed since John Locke? I conclude that there is a fatal contradiction between these two necessities; and that the survival of civilisation will require us to modify significantly

⁶³ This is roughly consistent with Purdy (2015), who estimates that the global human population was between one and ten million until the start of the agricultural revolution, for example.

⁶⁴ 1.5 billion is about the population at the turn of the twentieth century.

the powers we now grant to individual 'rights.' This social revolution will be painful, but it cannot, I think, be successfully evaded.

Dietz & O'Neill (2013) also say that overpopulation is a critical issue and that it should be stabilised using 'compassionate, non-coercive' methods, which may be less than politically palatable as a slogan or policy if only because it eerily echoes George W. Bush's 2000 presidential platform of 'compassionate conservatism'. An extreme view of the desirability of reducing human population is the *Voluntary Human Extinction Movement*, which has an extensive website and links on the issue:

Phasing out the human race by voluntarily ceasing to breed will allow Earth's biosphere to return to good health. Crowded conditions and resource shortages will improve as we become less dense (Knight 2016).

Of course it was not always thus. Further back in time, as discussed under 'technology' below, *Homo sapiens* was once an endangered species. DNA and archaeological evidence suggests that around 150,000 years ago our ancestors came close to extinction. This was due to an Ice Age that affected Africa - leaving perhaps an absolute total of only hundreds of people clinging to an existence on the southern coast. Genetic studies indicate that everyone now living is descended from this tiny number of ancestors (Marean 2010). We have come from a smudge of mere hundreds of us then to the prospect of a swarm of 51 billion of us by the twenty-third century. Between these extremes lies sustainability.

Anthropocene

Contrary to the long-held views of Paul Erlich and others, Andreas Malm and Alf Hornborg (2014, p. 4) argue in the *Anthropocene Review* that population growth is not a significant causal factor in the establishment of the Anthropocene epoch, in which the impact of humanity is profound. They point out that between 1820 and 2010, carbon dioxide emissions increased by more than 600 times, while population increased by less than seven times, "indicating that another, far more powerful engine must have driven the fires". And recently, there has been a negative correlation between population and carbon emissions – since 1985 population tended to rise fastest where emissions grew slowest, and vice versa (Satterthwaite, 2009). However, much of this relationship is due to the unique case of China, which has many people but low population growth and high emissions growth due to recent industrialisation.

A significant chunk of humanity is not party to the fossil economy at all. Hundreds of millions rely on non-fossil charcoal, firewood or organic waste such as dung for all domestic purposes. Satterthwaite (2009, pp. 547–550) concluded that one-sixth of the human population "best not be included in allocations of responsibility for GHG emissions", because their contribution is close to zero. Moreover, two billion people, or nearly one-third of humanity, have no access to electricity, and so "the difference in modern energy consumption between a subsistence pastoralist in the Sahel and an average Canadian may easily be larger than 1,000-fold" (Smil 2008, p. 259). Given these enormous variations over both time and space, human population seems far too slender an abstraction to carry the burden of causality.

Some of the apparent issue with population and sustainability is to do with simple accounting. We tend to divide nature amongst how many of us there are: *per capita*. Natural resources might appear to slow or shrink, simply because there are more people for them to be divided amongst:

the general trend is that population has been growing in most of the countries, exacerbating thereby the decline in natural capital [per capita] growth rates, as resources are accounted for among a larger number of people. The growth in population explains more than half of the changes in natural capital per capita in 13 out of 20 countries” (UNEP IWR 2012, p. 51).

Will Steffen (2014) points out that most of the economic growth in the last century did not result from population growth. Countries with higher population growth rates had lower increases in total GDP. This is consistent with both Satterthwaite and Smil above: impact depends on how much each person consumes, not just how many people there are. Of course politicians tend to gloss over the difference between growth in national GDP and growth in GDP *per person*. Without the population denominator it is not possible to know whether average affluence has increased, yet most public announcements of GDP growth are naked of how much they may be the result of population increase.

Still, popular opinions about the culpability of population are passionate and diverse, and may have to be politically accommodated. The following figure 22 shows an extract of online responses to a review of Elizabeth Kolbert’s ‘*The Sixth Extinction: An Unnatural History*’ that was published in *The Guardian* (McKie 2014). The last comment is at least succinct:

Figure 22. Online responses to review of *The Sixth Extinction: An Unnatural History*

budgie9999 16 Feb 2014 23:34
And your solution to the problems identified in this depressing book is...?

emmagoldmann 18 Feb 2014 8:51
And you've read it have you? Climate denier paid for troll I believe you have been caught out

TBombadil 17 Feb 2014 1:39

1. Reduce output of greenhouse gases as rapidly as possible.
2. Stop cutting down forests and encourage reforestation.
3. Ensure that wildlife corridors link wild areas together.
4. Create large protected areas of ocean, particularly round critical areas such as reefs.

eyeroller 17 Feb 2014 23:47
You forgot about drastically reducing the human population.

emmagoldmann 18 Feb 2014 8:50
5) Drastically reduce meat & dairy consumption

EnviroChem 17 Feb 2014 5:30
Letting career politicians dictate environmental policy is akin to placing them in charge of diagnosing and treat illness. It's not something they're capable of, not something they have any idea how to do. We need uncompromising science-based rapid policy.

Champing 17 Feb 2014 5:55
We, or at least some of us, have not progressed much since the 16th century:
<http://notrickszone.com/2014/02/16/uncovered-16th-century-hallucinatory-images-suggest-that-todays-climate-science-is-nothing-but-a-human-mental-disorder/>. It is all too easy to imagine the 16th century equivalents of Ms Kolbert in action. Oh brave new world that has such people in it!

algoyo 18 Feb 2014 2:26
The Holocene Extinction is part of a cycle caused by the presence of humans and our natural activities. It started thousands of years ago and is already underway. How we are to stop this? We'd have to stop being human. The fact we are causing it doesn't make it 'unnatural'. We are part of the biosphere and as such are also at risk of extinction. It's not so much "save the planet", but "save the humans".

Jon Davies 19 Feb 2014 1:38
Less people=less extinctions.

Source: McKie 2014, *The Guardian*.

Nevertheless, Fischetti (2014, p. 80), writing in the *Scientific American* has a sobering message about total population: that it will continue to grow until beyond 2100 is now looking more

likely. While Dorling (2014) and others were predicting that population would peak at less than ten billion by mid-century due to declining fertility in all regions, more recent evidence suggests that fertility in Africa will not decline as much as indicated and that as a result, global population may continue to increase to 10.9 billion by the end of the century.

Public policies

Aldous Huxley's utopian island of *Pala* introduced a population policy following experience of famine by its founder and new population growth spurred by better health and nutrition. In seeking a way between the unpleasant Malthusian horns of famine and 'moral restraint', the islanders decided that contraception "should be like education – free, tax-supported and, though not compulsory, as nearly as possible universal" (Huxley 1979 [1962], p. 97).

In reality, the two largest countries by population, China and India, together account for more than 2.6 billion people, well over a third of the world total (World Population Review 2015). Both have attempted to control population through public policies.

China's 'one-child policy' was introduced in 1979 in order to curb an explosive population growth that stemmed from the peace after the 1948 revolution. It was renounced only in 2015. The policy rewarded couples who had just one child with cash bonuses and better housing, and discouraged larger families with fines, forced abortions and official examinations for pregnancy by village family planning officers (Jian 2013). The one-child policy was resisted, especially in rural areas, where the predominance of agriculture dictates larger families; and within minority ethnic groups. In the first case two children were tolerated where the first was a girl, whereas in the second case the family was exempt. Nevertheless, the birth rate of 1.4 children per woman is now well below the rate of 2.1 needed to maintain the population level. As a result, China's population is ageing as the spectacular economic growth rate of the past three decades is slowing. The one-child policy has also resulted in a skewed ratio of men to women because boys are traditionally preferred to girls among Chinese families and therefore girl fetuses tend to be aborted more often than boys. Hence many men cannot find a marriage partner in China and often look to other countries for brides.

India's national family planning program began earlier – in 1952. It has since promoted contraceptive use, especially sterilisation, among married women. The 1992-93 National Family Health Survey (NFHS) found that almost 41 per cent of married women used contraception. Of those, two thirds had been sterilised, plus a further nine per cent of their husbands (Adlakha 1997, p. 3). After declaring a state of emergency in 1975, then Prime Minister Indira Gandhi led an aggressive campaign under which more than six million sterilisations, many forced, were performed. After violent protests, Mrs. Gandhi's party lost office at the 1977 elections and the number of sterilisations declined. However, since those times sterilisations have again been adopted as policy, more involving cash incentives. But the risks are still great: one hurried mass sterilisation of 83 women by one surgeon in one day resulted in 12 deaths from infection in 2014. The women were paid about 600 rupees, or about ten US dollars each (Barry & Raj 2014). Sterilisation remains common in India because it is cost-effective. It is also common in poorer countries such as Indonesia, especially among men.

The Chinese government is more authoritarian than its democratic Indian counterpart and this may have contributed to its more effective population control, although poverty reduction and urbanisation were also factors. Population control has been achieved at great cost, however. Women have had to undergo public scrutiny and forced abortions. The demographic profile of the country has distorted both between age groups and gender. The Indian program

included forced sterilisations and still results in death and suffering from inadequate medical procedures. Its effects fall mainly upon the poor. As a result, neither country has succeeded in using coercive policies to reduce population growth without consequent resentment.

The opposite approach was applied during the 1960s when the Romanian government banned both contraception and abortion in an attempt to increase its population, following considerable decline during the Second World War. But while the birthrate initially tripled, it soon returned to lower levels as families were too poor to support the extra children. Illegal abortions became widespread. Maternal mortality tripled. Many children grew up in orphanages. The architect of the policy, Nicolae Ceausescu, was executed when his government fell in 1989. The new government swiftly repealed the bans on contraception and abortion (Meadows 2008, p. 114).

This is not to say that population control cannot be achieved through non-coercive and less direct means. In crowded Bangladesh the demand for contraceptives outstrips supply⁶⁵ (Streatfield & Kamal 2013), but most families use family planning methods. Population growth slowed from over three per cent in the 1970s to 1.34 per cent in 2011. Educational and awareness programs have helped drive these results (Bangladesh Government 2012). In Ghana, women without education have an average of 5.7 children, women with secondary education have 3.2 and those tertiary educated 1.5 (Carrington 2014). Italy has changed from high fertility to a country almost devoid of children in two generations with the lowest birthrates in 150 years (Stanton 2015). Japan and Russia now both have declining populations, as would much of the developed world but for immigration. The public policy task is to apply such policies appropriately so that popular resentment is avoided. Poverty reduction and women's access to education are both proven indirect means of reducing population pressures. Consistent with Huxley's *Pala* (1979), according to the UN the relatively simple measure of providing access to dependable contraception may be the single greatest contribution to population restraint that can be made (Islam 2015, s. 8).

Evaluation

While the issue of human population growth appears less important now that the rate of growth is slowing, our mounting numbers over the present century are a significant threat to sustainability due to the resources required and the waste produced, in a world where we are already exceeding the capacity of the planet.

Recognising that it is very difficult to halt the momentum of population growth due to its course over generations, the key question is how to contain population increases without using coercive methods. The recent population decline in Japan and Russia and the natural decrease in much of Europe⁶⁶ have occurred without compulsion and indicate how public policy might be applied. Migration, industrialisation, urbanisation, education, gender equality and the availability of contraception are all agents of population restraint. To encourage these agents will be to brake our impact upon our planet where there are already too many of us for the Earth to support.

Otherwise, inevitably, much of the world will look increasingly like Hong Kong does today – but without the beauty of its harbour. More like Mexico City or Lagos. Like Karachi or Beijing or Chongqing. If our civilisation remains viable and irrespective of an increase in loneliness, greater density through urbanisation seems inevitable. Sustainability depends on it.

⁶⁵ Largely due to bureaucratic procedures and logistics of procurement.

⁶⁶ Population growth in much of Europe tends to be from immigration rather than natural increase.

Chapter 5. Affluence

*The inherent vice of capitalism is the unequal sharing of blessings – Winston Churchill 1945.*⁶⁷

It is commonly asserted that the average contemporary Westerner enjoys greater affluence than the kings and emperors of the pre-industrial era. Certainly an investigation of the palace of Suleiman the Magnificent in Istanbul is instructive: While between 1520 and 1566 he led an empire controlling much of South Eastern Europe, Western Asia, the Caucasus and Northern Africa, Suleiman's personal lavatory, for example, although lined in marble may as well have been of concrete. It essentially consisted of a hole in the floor. He possessed no transport apart from that which meandered at the pace of a horse or with the lassitude of sail. He knew nothing of flight, except that of birds, bats and insects. He communicated at a distance only by messenger.⁶⁸ His entertainment was necessarily live and his literature limited.

This chapter discusses the relationship of affluence to human well-being and the importance of nature in the provision of wealth. It argues that the economics of capitalism have distorted humanity's relationship with the natural world and how alternative forms of measurement, if genuinely adopted by important institutions, may clarify that bond.

While it may be true of affluence and the average Westerner, it is probably not true of the average Southerner that she is better off than an ancient emperor. Her lavatory will not be lined in marble. It will at best be a hole on the floor. There may well be no floor. It will probably not be a flushing system connected to a sewer. It may be at some distance from her dwelling, or not a facility at all. It may be dangerous for her to even venture there for fear of violence (McCarthy 2014). She may know of crowded trucks and buses (especially in Africa) and trains (especially in India). Aircraft may be seen far above in the sky. She may possess a mobile phone and watch films using a communal diesel generator to power the DVD player. Neither, however, will protect her from the risk of death in childbirth or from infection by malaria, tuberculosis or HIV. She may well be one of billions who are vulnerable to multi-dimensional poverty (UNHDR 2014, p. 19).

The affluent Westerner and the impoverished Southerner are contemporary extremes in geography as well as recent history. Arguably they depend on each other: As Marshall McLuhan (1964) famously wrote, "affluence creates poverty", meaning that the poor are poor because the rich are rich; wealth depends on the exploitation of others. However, the observation that the sun causes poverty does not hold throughout history. Ancient Egypt, the Khmer empire, and the Mayans were all civilisations of immense wealth, yet arose in tropical settings. Arguably all three failed to adapt to changing circumstance; the Egyptians failed to innovate,⁶⁹ the Khmer did not cope with degradation of their irrigation system and Mayan agriculture failed to cope with drought (Diamond 2003). Today, the tropical city-states of Singapore and Hong Kong are icons of wealth. If it was not the sun that caused the poverty of the South, then what is it that causes the wealth of the West? Perhaps it is that the 'North

⁶⁷ Churchill's pointed corollary was "*The inherent virtue of socialism is the equal sharing of miseries*", House of Commons, 22 October 1945.

⁶⁸ The system of semaphores originally implemented by Claude Chappe shortly after the French Revolution could transmit messages more quickly and was a significant advance on the horse. However, it required the construction of towers and equipment, was subject to the vagaries of weather, and lacked privacy as well as linguistic subtlety.

⁶⁹ Staying with archaic bronze weapons when their enemies, the Hittites, used iron, for example.

wind made the Vikings', or that overexploitation of natural resources – the denuded forest – led to the use of coal, in which power is concentrated (Nef 1977, pp. 140-141).

In stark contrast with people of the South, it was only during the twentieth century that it became possible for the majority of ordinary people in the West to enjoy unprecedented affluence – on a scale unimaginable before the modern era. This was an affluence free from past abject drudgery and the daily struggle for survival. It was an affluence that included the near universal availability of flushing lavatories. For the first time in human history it was possible for vast numbers of people to live fully rather than subsist, to freely exercise desires for leisure, for art and for knowledge beyond that of immediate need for food, shelter and companionship. Although interrupted by war and economic depression, this new widespread affluence was a product of three key factors – a new economic system, the exploitation of energy reserves and mass production.

The new economic system was based on “the lure of gain” for individuals effected through the market system, “the most important revolution, from the point of view of shaping modern society, that ever took place” (Heilbroner 1983, p. 17). This society-wide economic system – capitalism – was the third form of societal organisation that has evolved. The first was traditional (and largely agricultural), in which societies' tasks were allocated according to custom, where son followed father, daughter followed mother, where occupation was often attached to caste. The second form was through command, the whip of authoritarian rule, whereby the pyramids were built and in more recent times, Soviet farms collectivised. Neither of these economic systems necessarily involved the transfer of money throughout society. But it was this third new system that introduced the novel idea of individual gain that, with widespread use of money both as wages and as wealth, could build upon earlier gains and involve whole societies in the advance of affluence. The reinvention of money during the Middle Ages was critical in this new system because, instead of barter, money required acceptance of the concept of value. Once this abstract concept was established, it led to its expression in a market that could be leveraged and exploited (Sattin 2014).

The exploitation of energy reserves remains central to this new economic system and to the affluence it has created.⁷⁰ During the nineteenth century, the primacy of coal was established in fuelling new secondary industries, which could be located where labour was cheap, rather than where waterwheels could be powered (Klein 2014, p. 172). The conversion of coal to heat allowed steel production, mass transport (railways), mass electrification and new factories producing affordable consumer goods. During the twentieth century, oil and gas made individual autonomous transport (cars) and aircraft feasible. This fossil-based energy is highly concentrated, considerably more so than primitive windmill, waterwheel or animal power. Accordingly, without the extensive use of concentrated energy, modern affluence would not be possible. Metals, electricity and consumer goods cannot be provided on a mass scale by a horse plodding around the axis of some crude turbine. Rather, billions of tonnes of coal and billions of barrels of oil⁷¹ – or their equivalent – are needed each year to enable the elements of mass affluence.

Mass production techniques involved new factories producing affordable consumer goods. When applied to complex manufactures and use of the assembly line, this technique became

⁷⁰ Indeed, one US physicist asserts that the maintenance of societal wealth is directly proportionate to the generation of energy (Garrett 2014).

⁷¹ According to the International Energy Association (IEA), global coal consumption in 2012 was about 7.7 billion tonnes, while oil consumption was about 32 billion barrels a year or 90 million barrels a day.

known as 'Fordism', after Henry Ford the car manufacturer,⁷² a term coined by Antonio Gramsci in his 1934 essay *Americanism and Fordism*. But the most important aspect of Fordism was its virtuous re-cycling of profits through increased workers' wages, that then enabled the workers to buy the cars they made, that then enabled higher production, enabling lower unit costs through economies of scale and so on. Gramsci was sceptical about this virtuous cycle and questioned "the so-called 'high wages' paid by Fordised and rationalised industry", rather suggesting that Fordism was "the ultimate stage in the process of progressive attempts by industry to overcome the law of the tendency of the rate of profit to fall" (Gramsci 1999 [1934], pp. 562-563). Growing affluence based on reducing the relative costs of new complex manufactures remains with us today. However, much of the lower costs of, for example, cars, apparel and homewares in the West is now due to exploiting the lower wage structures and economies of scale of the East, foreshadowed by Gramsci as part of an 'international division of labour' (Ibid, p. 607).

There are parallels between the economies of the early twentieth and early twenty-first centuries. In both eras the prices of iconic items continually fell while quality improved, due to the effect of scale:

Economies of scale allowed the robber barons to keep reducing prices and improving quality. Henry Ford cut the price of his Model T from \$850 in its first year of production to \$360 in 1916. In 1924 you could buy a much better car for just \$290. The silicon sultans performed exactly the same trick. The price of computer equipment, adjusted for quality and inflation, has declined by 16 per cent a year over the five decades from 1959 to 2009. Each iPhone contains the same amount of computing power as was housed in MIT in 1960 (*The Economist* 2015a).

Definition

The word 'affluence' appeared in English around the mid-fourteenth century, according to the Oxford English Dictionary, and derives from the Old French *affluence* and Latin *affluentia*, "a plentiful flowing, an abundance, rich, copious", including a sense of 'wealth' from about 1600, from the notion of "a plentiful flow" of the gifts of fortune. The word 'wealth' is from the mid-thirteenth century Middle English 'wele' or 'well-being' and is based on the analogy of 'health'. In economics, 'wealth' means 'the sum of all goods and services that have an exchange value' but it originally meant 'happiness', as well as its contemporary meaning of 'prosperity in abundance of possessions or riches'. The association of affluence with wealth and thus with happiness may have been lost as a meaning because objectively the connection is in fact, not entirely clear. Rather, it is more of a paradox:

the happiness - income paradox is this: at a point in time happiness varies directly with income, but over time happiness does not increase when a country's income increases (Easterlin & Angelescu 2009, p. 2).

This finding is based on an analysis of responses to questionnaires about life satisfaction and income in 37 countries in different stages of development.

The same study shows that people are more dismayed about loss of income than we are elated by an equivalent gain (Ibid. p. 12). In a similar vein, at the intersection of economics and psychology, there is also the profound observation that affluence is relative as much as it

⁷² The Ford Motor Company was one of the first multi-national corporations (MNCs). After incorporation in 1903 it expanded production to Canada in 1904, to Europe in 1917 and to Australia in 1925.

is absolute. It is distressing if we are less affluent than our friends and neighbours and comforting if we are wealthier, irrespective of absolute levels of affluence (Veblen 1899, ch. 4, Solnick & Hemenway 1998, pp. 380-381). Thorsten Veblen, who coined the term 'conspicuous consumption', detailed the display behaviours of the wealthy that both symbolised and underscored their relative material superiority during the Golden Age of the late nineteenth century.⁷³ However, the abundance now generally enjoyed in the West is conspicuous relative to the scarcity of the South. And it appears to be built on fragile foundations.

At the individual psychological level, western affluence has also produced a dysfunctional behaviour known as hoarding. Cherrier & Ponnor (2006, p. 26) make a distinction between collectors, functional hoarders and non-functional hoarders. While collectors enjoy societal approval for their organised collections based on aesthetic or historical value, functional hoarders risk disapproval of family and friends because they find it difficult to part with many useless items for sentimental reasons or perceptions of wastefulness. Non-functional hoarders, however, risk not only societal intervention but also their own well-being and safety as a result of compulsive accumulations of valueless items. There is evidence that some of this hoarding behaviour may be due to perceptions of resource shortage originating, for example, during the Depression, during rationing in the 1940s or during the oil crises of the mid-1970s. Nevertheless, it is facilitated by affluence. Basic material goods in the twentieth and twenty-first centuries are cheap and diverse. In many cases they are made to be disposable, but instead, this stuff is hoarded as a form of psychological security. Sometimes its manifestation is extreme:

The Collyer brothers, for example, died in the United States in 1947 due to over-cluttered space. It is reported that their house contained 136 tons of refuse. One brother was buried alive when piles of rubbish collapsed on him, leaving his blind brother starving to death (Ibid, p. 6).

The world's first shopping mall, 'Southdale' near Minneapolis in Minnesota, started in 1954 in a building complex purpose-designed by Victor Gruen and "spread like an epidemic across the USA and the rest of the world" along with convention centres, sports arenas and indoor theme parks. Such malls are an embodiment of mass consumerism, and despite the current prevalence of online shopping continue to exert a powerful attraction throughout the world. The term 'Gruen transfer' refers to the sense of disorientation many people feel when they first enter these spaces such that they forget their original intentions and buy more than initially planned (Sloterdijk 2005, p. 274).

Stuart Jeffries points to the stress associated with too much material choice that consumerism encourages:

Once upon a time in Springfield, the Simpson family visited a new supermarket. *Monstromart's* slogan was "where shopping is a baffling ordeal". Product choice was unlimited, shelving reached the ceiling, nutmeg came in 12lb boxes and the express checkout had a sign reading, "1,000 items or less". In the end the Simpsons returned to Apu's Kwik-E-Mart (Jeffries 2015, para. 1).

Aristotle viewed wealth as either 'unnatural' if it were attained through trade, or 'natural' if attained through "skilful management of house and land". Trade is unnatural because it involves using things for other than their natural purpose, and because it involves money,

⁷³ Although he was largely anticipated by Adam Smith (1776, p. 202): "With the greater part of rich people, the chief enjoyment of riches consists in the parade of riches".

which has no real use other than exchange. Thus the most hated, most unnatural form of wealth is that produced from money itself – usury – the lending of money at interest (Aristotle 1952 [c. 330BC], 1258b).

Aristotle may have only been reflecting his class interests, however. Throughout history debtors have disapproved of interest while creditors have the opposite attitude. Because Greek philosophers were aligned with the landowning class who were often in debt, they did not like usury (Russell 1980 [1946], p. 198). Nevertheless, Aristotle presented a more profound insight: wealth of the household is limited, but monetary wealth, the spurious kind, has no limit and nor has the desire for it. As “money supplants other values and becomes their only measure”, no matter how affluent a person becomes, there is always a desire for more (Harvey 2014, p. 277).

Nonetheless, as far as the relationship between affluence and sustainability is concerned, there are several key dimensions. These include how affluence is measured, created and distributed, and how it relates to the environment, including its effects on resources, energy, species and habitats.

Measurement

While the invention and widespread use of money enabled the easy storage, measurement and accumulation of wealth, only since the 1930s were detailed national accounts constructed for government policies, especially in the UK and US, due to pressures of the Depression and in preparation for the Second World War (Van Dieren 1995, p. 39, Coyle 2014, p. 12). Up until that point, ‘the economy’ was essentially the private sector only. Government was excluded because it had minimal input into production. It was only since the Depression and the supporting *General Theory* of J.M. Keynes (1936)⁷⁴ that government became significant in economic growth, especially in the US, Europe and the remainder of the West. In the Communist states of course, government was already pre-eminent.

The universal use of GDP to measure national wealth and economic growth is even more recent. While the measure was formally established in 1953 through the UN statistical system, its universal use did not occur until towards the end of last century. Up until then GDP was one of several similar but competing concepts, in particular Gross National Product (GNP), which measures the net wealth generated by national citizens and corporations, irrespective of their location. GDP, however, is the market value of everything produced within a country’s borders. With GNP, a US corporation operating in say Botswana, would have its profits counted towards US GNP. Conversely a foreign firm operating in the US would not have its profits counted towards US national figure. Gross National Income (GNI) is the same concept as GNP but uses an income rather than a production measure. One reason for the persistence of GNP and GNI as a measure of national economic output in the US, may be that unlike most countries, US income tax is payable irrespective of in which country its citizens reside. At the global level of course, all three measures are theoretically equal since total exports⁷⁵ should equal total imports and production is accounted for but once in each system.

⁷⁴ Keynes’ *The General Theory of Employment, Interest, and Money* was published in 1936, some years after Franklin Roosevelt’s practical application of demand creation through *New Deal* government spending on infrastructure, employment and welfare programs.

⁷⁵ In practice however, total global exports tend to be higher than imports, probably due to political pressures to produce favorable statistics. Interplanetary imports and exports (soil, rocks, spacecraft, solar-powered robotic cars) are not usually ascribed a monetary value, but may have to be in the foreseeable future as their volume and total value increase.

The gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything in short, except that which makes life worthwhile – Robert Kennedy, speech at University of Kansas, 1968.

The most common way of measuring GDP is the expenditure method: $GDP = \text{consumption expenditure} + \text{investment expenditure} + \text{government spending} + (\text{exports} - \text{imports})$, or, $GDP = C + I + G + (X - M)$. Thus GDP measures both total production and total consumption, which are directly related. Interestingly, Simon Kuznets, who was later awarded a Nobel prize for this work, was in charge of developing a comprehensive system of national accounts in the US during the Roosevelt years. He wanted the accounts to measure human *welfare*, not just total output or consumption. Accordingly, he argued – unsuccessfully – that the new national income measure should subtract all expenditure on armaments, advertising, “speculative activities” and “necessary evils”, like subways. In this, however, he was at odds with the spirit of the time, and particularly with Roosevelt who wanted government spending to be included as a positive economic contributor and thus demonstrate that the US economy was growing again post-Depression (Coyle 2014, pp. 13-15). Today, the resultant GDP measures without moral perspective. A billion dollars’ worth of nuclear bombs is counted as exactly equal to a billion dollars’ worth of baby food.

But irrespective of Kuznets’ or FDR’s views on what should be included, this dimension is quantitative, which tends to lead to an over-emphasis on the notion of ‘growth’ at the expense of ‘development’. Former World Bank ecological economist Herman Daly (1990, p. 1) argues that the distinction between ‘growth’ and ‘development’ is that the former is about an increase in size, whereas the latter is about qualitative improvement. Thus ultimately the human global economy cannot grow to be more than the finite global ecosystem of which it is part. Yet while economic growth cannot be sustainable in the longer term, it is possible for economic development to be sustainable, because the global ecosystem develops without growing. In measuring wealth as the quantitative GDP, ironically we tend to value that which leads to unsustainability and its own negation.

Before that point is reached, however, when comparing the wealth of different countries, it is important to be clear about what is meant by the size of an economy and how it relates to affluence. The US has the world’s largest economy and China the second largest. However, this can be measured in nominal as well as in purchasing power parity (PPP) terms, where the value of goods and services consumed is weighted according to the cost of living in each country. For example, if ten dollars (or its exchange currency) buys one Happy Meal in the US, but two Happy Meals in China, then each dollar equivalent of GDP in China is worth twice each dollar of GDP in the US, at least as far as Happy Meals are concerned. The difficulty in PPP measurement is ensuring that the basket of goods used to indicate purchasing power is representative of consumption in both countries. In nominal terms, US GDP was about USD16 trillion compared with China’s GDP of about USD9 trillion in 2013. But in PPP terms China’s GDP is nearly the same as the US, according to the World Bank (2014b). However, in terms of personal affluence, both are distorted comparisons. China has more than four times the US population; therefore the average American is more than four times as affluent as their Chinese counterpart in PPP terms⁷⁶. It is this measure – GDP per person (PPP) – that is more

⁷⁶ And more than eight times as affluent in nominal terms

relevant when discussing relative national affluence as well as, more importantly, its impact on the entire planet.

It is also important to be aware that GDP is a measure of production, consumption or income. It is a gauge of flow. It does not measure the stock of accumulated wealth. Thomas Picketty (2014, p. 463) points out that more and more countries are becoming owned by their own billionaires, including especially the established billionaires of Europe, rather than being taken over by foreign wealth. Thus, consistent with the fears of Aristotle, wealth is accumulating and concentrating within national borders as much as it is concentrated in the West compared with the South.

Hazel Henderson (2014), among others including Joe Stiglitz, believes that the measurement of GDP contributes to a debt imbalance and therefore artificially weakens national economies. Unlike business accounts with flows of income and expenditure and stocks of assets and liabilities, national accounts lack assets:

So, the Grossly Distorted Picture in current GDP only records levels of public debt for vital infrastructure and public services (police, fire protection, teachers, etc.). Omitted is an asset side to account for valuable taxpayer investments in public infrastructure: transport, ports, railways, schools, etc., many of which last for over 50 years and should be carried on the books, just as they are on corporate balance sheets. Imagine trying to run a company this way! (Henderson 2014).

Governments focus on GDP, however, because not only is it a simple measure that correlates with other indicators of well-being (such as employment and education levels), but also that it can be influenced by government policy in the medium term. Other indicators also can be influenced by government policy, but few combine all these apparent virtues as well as does GDP.

Wealth creation

The concept of national (and now global) wealth is central to political economy and economics generally, and is generally attributed to Adam Smith's *Wealth of Nations* (1776). In fact, the notion of national wealth as a capital stock appeared in texts that predate Smith's works. In *A Discourse of Money* for example, John Briscoe (1696, p. 198) writes of "the capital stock of national treasure". Andrew Hooke, in his *Essay on the National Debt and National Capital* (1750), treats the "national capital" as consisting of (1) "cash, stock, or coin," (2) "personal stock" or "wrought plate & bullion, jewels, rings, furniture, apparel, shipping, stock-in-trade, stock for consumption, and live-stock of capital," and (3) "land stock," "the value of all the lands in the kingdom."

During the eighteenth century the French physiocrats⁷⁷ developed an economic theory whereby national wealth is composed of the value of agricultural land and its produce, due to productive work. According to its proponents such as François Quesnay (1694–1774) and Anne-Robert-Jacques Turgot (1727–1781), capital (derived from surplus saved) is necessary for economic growth and economies function best where each participant is free to pursue their own wants (*'laissez-faire'*).

⁷⁷ Physiocracy: from the Greek 'government of nature'.

When Adam Smith took the term 'capital' in hand, he began by distinguishing capital from interest. In his *Lectures on Jurisprudence* it first appears as a sum of money lent, as opposed to the interest paid, on the loan.

When a sum of money is lent to a private person, the creditor can come upon the debtor when he pleases for both capital and interest; but it is not on this footing that the government borrows money; they give you a right to perpetual annuity of 3 or 4 per cent, but not to re-demand your capital (Smith 1766, p. 248).

Much of a century after Smith, Engels was more concerned with how the concept of national wealth masked poverty:

The term national wealth has only arisen as a result of the liberal economists' passion for generalisation. As long as private property exists, this term has no meaning. The "national wealth" of the English is very great and yet they are the poorest people under the sun. One must either discard this term completely, or accept such premises as give it meaning. Similarly, with the terms national economy and political or public economy. In the present circumstances that science ought to be called private economy, for its public connections exist only for the sake of private property (Engels 1844, para 13).

More generally, wealth is created through the application of human labour, according to Adam Smith, and this was the original basis of exchange value. The exchange value of a good, Smith said in the *Wealth of Nations*, is determined by the amount of labour it contains in its production. In a primitive society it is the only way of determining how goods can be exchanged. If it takes twice the labour to kill a beaver as it does a deer, then one beaver is worth two deer (Smith 1952 [1776], p. 20). But in advanced societies, the price of a good includes three factors – labour, the owner's profit plus rent. However, "the real value" of all three components, "is measured by the quantity of labour which they can, each of them, purchase or command" (Smith 1952 [1776], p. 21). Consistent with Smith's insight, machinery and technologies that facilitate the production of goods in modern economies are simply stored labour, since it is human labour that enabled their conception and creation. Skill is the embodiment of earlier labour. Services, as distinct from goods, are still more directly composed of labour.

Other theorists, notably Karl Marx, based much of their analysis on this concept, in particular that the surplus value inherent in a good derives from the value of the labour it embodies beyond that needed for the subsistence of the labourer (Wolff 2011, s. 3). Marx's model of perfect contemporary capitalism demonstrated that the only source of profit was this surplus value, because the labourer must sell his labour at a subsistence rate, considerably less than the value of labour he makes available to the capitalist. The difference is the profit that fuels capitalism (Heilbroner 1983, pp. 120-121).

While the labour theory of value has been described as "an appalling jumble of ideas" (Whitaker (2001 [1904], p. 6), it did underline the central importance of labour to political economics and the creation of wealth. That organization of labour to create wealth, according to Smith in his early *Lectures on Jurisprudence*, progressed in four societal stages:

...hunting, pasturage, farming, and commerce. If a number of persons were shipwrecked on a desert island their first sustenance would be from the fruits which the soil naturally produced, and the wild beasts which they could kill. As these could

not at all times be sufficient, they come at last to tame some of the wild-beasts that they might always have them at hand. In process of time even these would not be sufficient, and as they saw the Earth naturally produce considerable quantities of vegetables of its own accord they would think of cultivating it so that it might produce more of them...The age of commerce naturally succeeds that of agriculture. As men could now confine themselves to one species of labour, they would naturally exchange the surplus of their own commodity for that of another of which they stood in need (Smith 2005 [1766], pp. 522-523).

Smith was writing at the brink of the industrial era, which was unknown to him. However, affluence, in the sense of the accumulation of wealth, increasingly depended on possession of the means of production. Therefore, in line with Smith's societal stages, the means of production was for hunters the spear, for herders the stock, for farmers the land and for entrepreneurs the firm. Further, the associated development from communal to private ownership enabled wealth to be concentrated in fewer hands. In the industrial era, factory ownership was key to affluence. In the post-industrial era it is more the ownership of a technology or 'intellectual property' that is the source of affluence, as no doubt Bill Gates and the geeks of Silicon Valley would concur. Especially in its patent-protected recent forms, technology tends to concentrate affluence.

Thus in both classical and Marxist political economy, nature is peripheral. Human intervention, invention and organization is presumed more significant. Smith's desert island illustration, however, did begin to recognise the importance of the natural world. It is the source of sustenance from gathering and cultivation, from hunting and husbandry. Human labour does not produce wealth from nothing. It produces wealth from the natural world. Marx too, was aware of nature and its relationship to human wealth (Bellamy Foster 2000). Engels also knew that wealth ultimately derives from nature: "labour is the source of all wealth...next to nature, which supplies it with the material that it converts into wealth" (Engels 1925 [1883], p. 452).

That ultimate foundation of wealth, however, "based on ever-more alarming environmental reports"⁷⁸ is now dramatically "sinking under the weight of demands to supply more resources and absorb more wastes" (Gale 2014, p. 1).

Indeed, capitalism is built on unending economic growth:

A purely private enterprise system can only function if companies can obtain sufficient profits which in turn requires that the selling price of goods exceeds the costs of production. This means that the selling price must exceed the spending power that has been distributed through payments to factor inputs. Hence, to ensure sufficient "aggregate demand" to clear the market, additional spending power is required from some other source. In a purely private enterprise system, this normally derives from investment in new productive capacity which will increase the amount or quality of goods supplied, but only after some interval. Investment therefore serves the dual role of increasing productive capacity and creating additional demand to clear the market of whatever has already been produced (Sorell 2010, p. 1797).

As far as consumption is concerned, the economist Kenneth Boulding was one of the first of that discipline, however, to point out that "the closed Earth of the future requires economic principles which are somewhat different from those of the open Earth of the past" (Boulding

⁷⁸Gale cites reports about climate change (IPCC 2013), forestry and fisheries depletion (FAO 2010; FAO 2014), ocean acidification (UNEP 2010), and species extinction (MEA 2005).

1966 p. 10), a challenge to economists to re-think the centrality of growth, which has yet to be fully accepted. This may be because he was less than complimentary to others of his profession: "Anyone who believes exponential growth can go on forever is either a madman or an economist". Redclift (1993, p. 19) accuses "modern economics" of causing "unsustainable development" due to the pursuit of growth at the expense of ecological consequence. This "has its roots in the classical paradigm which informed both market economies and state socialist ones".

And economic growth does not even translate to more happiness. Easterlin & Angelescu's (2009, p. 2) study of 37 countries showed, as with income relativities, there is no relationship between the rate of growth of GDP per person and increase in happiness. Whilst there may be short-term associations between the growth of happiness and income due to fluctuations in macroeconomic conditions, the long-term relationship "is nil" (Ibid). That our happiness has little to do with economic growth is an encouragement for environmentalists who advocate restraint in production and consumption (Trainer 1985, Alexander 2015), and an obstacle for development economists who advocate continuous growth.

But wealth is not necessarily material. Engel's friend, Karl Marx, writing his notes in the *Grundrisse* approvingly quotes an earlier view of Charles Dilke – that true national wealth is not a matter of money or other capital, but rather consists of more free time for everyone:

Truly wealthy a nation, when the working day is 6 rather than 12 hours. Wealth is not command over surplus labour time' (real wealth), 'but rather, disposable time outside that needed in direct production, for every individual and the whole' (Dilke 1821, p. 6, quoted in Marx 1973 [1861], p. 706)

Charles Dilke's view of wealth as ultimately free time is in turn probably based on that of the utopian socialist, William Godwin⁷⁹ (1793): "Is there not a state of society beyond that needed for production...in which leisure shall be made the inheritance of every one of its members?". Indeed, in this century there have been studies of the phenomenon of "downshifting", whereby significant numbers of people in affluent societies choose simpler, cheaper lives that consume less while providing more leisure and pleasurable time outside of 'the rat race'. Involving around 20 per cent of adults in both the US and Australia, these people voluntarily forgo what they regard as unneeded income and material goods, and are mostly happy with their decisions. The most prominent reason for downshifting is that old trope of retiring politicians – 'to spend more time with their family' (Hamilton & Mail 2003, p. 20), but probably meant more sincerely.⁸⁰

This profoundly different view of wealth as free time is arguably now within the grasp of contemporary advanced economies as automation replaces unskilled labour. To a significant extent, now even the skilled labour of, for example, journalists, accountants and marketing executives is demonstrably replaceable. In ancient times it was the few who enjoyed the wealth of leisure, the freedom to create rather than the drudge of repetitive unskilled labour. Now that machines are capable of that production as well as routine labour of the mind, the political issue again is distribution.

⁷⁹ Husband of Mary Wollstonecraft and father of Mary Shelley.

⁸⁰ However, a more recent (albeit limited) international comparison did not support the notion that 'post-materialist values' had any influence on consumption in industrially advanced countries such as Germany, Canada and Sweden (Eklund 2012, p. 27).

Wealth distribution

In Plato's Republic its distribution would result in an inequality of wealth no more than four to one, otherwise it threatened social order (1952 [c.380BC], s. 744). That ratio has been since far exceeded in modern republics, but there remains a certain wariness about its implications for unrest. The 1789 French and the 1917 Russian revolutions are obvious examples of its menace.

While there were minimum income payments by the state in eighteenth century England via the 1795 Speenhamland⁸¹ Law, abandoned because it inhibited the creation of an industrial labour market (Polanyi 2001 [1944], pp. 81-82), industrialisation at first brought with it greater inequality, justified as virtue. During the Victorian era there was a tendency to assert various political and economic doctrines as 'iron laws', so as to imply their universality as if they were the enduring *principia* of some economic Isaac Newton. They include the 'iron law of wages' attributed to, amongst others, Malthus and Ricardo, which states that wages of labourers will tend to fall to the minimum for human subsistence, such is the unfortunate tendency for the poor to reproduce themselves in numbers that create an oversupply of their kind. This is associated with a latterly named 'iron law of population', which states that a rapidly increasing population inevitably leads to poverty.

Hence it became virtuous for harsh measures to be taken against the poor – as if they were some undesirable separate species. If the poor were provided with more than the barest of necessities via wages or social welfare measures, then they would simply increase their numbers through ill-discipline and fornication. Wages would thus fall still further, below subsistence levels, to their greater detriment. How kind it was therefore to be cruel; how much better for the poor to be contained in a misery that made possible their subsistence, but no more. There was no affluence for the masses to be found in Victorian economic theory cast as enduring truth.

However, the beginnings of the modern era began to bring leverage to the cousins of these early wage slaves in the former colonies of Australasia and North America. Universal suffrage, unions and the creation of political movements entwined to result in wages that provided "reasonable comfort" in Justice Higgins' decision of 1907 in Australia (Robbins et al 2005, p. 488) and the beginnings of welfare measures in the US during the Depression. Winston Churchill, who observed in 1945 that capitalism is good at accumulating wealth, but poor at distributing it, nonetheless opposed welfare measures in post-war UK and was dismissed by electors in the same year.

As welfare measures took hold in the West, a degree of universal affluence was identified mid-century in the work of Simon Kuznets. After his involvement in quantifying national income, Kuznets found evidence for an inverted U-shaped curve that described the relationship between inequality and economic development. As economic development proceeds and more people take advantage of greater opportunities, average incomes rise. At first there is increasing inequality as only a few benefit, which then peaks when the entire population is involved in the more developed economy. Inequality then begins to fall and return to earlier levels as progressive taxation and social welfare programs are implemented.

Margaret Thatcher and Ronald Reagan, who both championed the resurrection of economic liberalism during the 1980s, oversaw rising inequality in the West as wealth generation was

⁸¹ The Speenhamland Law guaranteed a family income based on the price of a loaf of bread.

regarded as more important than distribution, their national economies having suffered a decade of stagnation.⁸²

The predominance of neoliberalism has since been undermined by the global financial crisis of 2008 and the subsequent continuing global recession. Recently, French economist Thomas Piketty's *Capital in the Twenty-First Century* (2014) created a scholarly storm with its thesis that in the longer-term since the Industrial Revolution, inequality will continue to increase, as the return on capital normally exceeds income from labour. Inequality grows especially in times of political stability, but can be reversed in times of crisis such as the Depression and the two world wars. This contradicts earlier assumptions and narrow evidence that increasing economic growth produces greater equality (Kuznets 1955).

Piketty's research greatly widens the scope of Kuznets' earlier inquiry into inequality and encompasses it in a manner that recalls Einstein's subsumption of Newton. Kuznets had found that inequality tended to decline over time in developed economies. Piketty, by analysing a much greater range of data covering most major economies over the past 300 years, shows that Kuznets was accurate, but that the period he chose (1913-1948) was an aberration in the long-term trend of growing inequality. What appeared to Kuznets as a compression of wealth disparities was due to the disruption of the two world wars and the effects of reconstruction. When less chaotic times returned, wealth – including income – again resumed its long march to widening disparity. Piketty's findings have since been dramatically extended to encompass even ancient times. The only factors that reduce otherwise inevitable inequality are 'the four horsemen of levelling' – mass warfare, revolution, state failure, and pandemics (Scheidel 2017).

Importantly, Piketty surmises that economists became uninterested in inequality and its risks after Kuznets mid-century. Although it was a central concern of nineteenth century political economists, such as Marx, Engels and Ricardo, inequality became no longer an issue because of his reassurance. But Piketty goes further in showing how Kuznets brought his immense prestige as a Nobel laureate and president of the American Economics Association (AEA) to bear on the issue. For the first time the dire predictions of Marx – growing inequality, overproduction, collapse of demand, impoverishment, revolution – were apparently disproven, based on Kuznet's detailed research of then newly available data. In future, according to Kuznets' enthusiastic 1954 speech to the Association,⁸³ providing that countries followed the US model, economic growth would not only diminish poverty, but society would become more equal as development matured. In the middle of the Cold War, for America and the West this was good news indeed.

Kuznets was careful to decorate his crucial news with qualification, but any proviso was soon swept away behind the word 'however':

No adequate empirical evidence is available for checking this conjecture of a long secular⁸⁴ swing in income inequality; nor can the phases be dated precisely. However, to make it more specific, I would place the early phase in which income inequality might have been widening, from about 1780 to 1850 in England; from about 1840 to 1890, and particularly from 1870 on in the United States; and, from the 1840's to the 1890's in Germany (Kuznets 1955, p. 19).

⁸² Especially the 'stagflation' due to the OPEC-induced oil price increases.

⁸³ Kuznets speech to the American Economics Association was made in December 1954 and was published in the Association's journal in 1955.

⁸⁴ The word 'secular' refers to 'long-term' rather than cyclical trends.

These three countries, England,⁸⁵ the US and Germany, are the only three that Kuznets was able to study in detail. Picketty's sources are not only much more extensive in time, but also many more countries are covered.

It is hard to overstate Kuznets' prestige before Picketty arrived. Not only was Kuznets a Nobel laureate and president of the AEA, he was also one of the economists central to the development of national accounts and the very concept of GDP. Earlier he had been trusted by Franklin Roosevelt to provide the constructs and data to enable the recovery of the US and the world from the Great Depression of the 1930s (Coyle 2014, pp. 12-13). He was, at least until 2014 and Picketty, regarded as one of the most important authorities on the effects of economic development and poverty reduction. The 'Kuznets curve' that describes economic development and inequality, the 'Kuznets ratio' that relates income of the highest-earning households against the lowest, and the 'environmental Kuznets curve' that relates environmental degradation against economic development are all indications of his regard. It is a tragic irony that one of the conclusions of his watershed 1954 speech concerns Marx and an "overgeneralization" of tendencies not properly understood:

It is also possible that much of Marxian economics may be an overgeneralization of imperfectly understood trends in England during the first half of the nineteenth century when income inequality may have widened; and that extrapolations of these trends (e.g. increasing misery of the working classes, polarization of society, etc.) proved wrong because due regard was not given to the possible effects upon the economic and social structure of technological changes, extension of the economic system to much of the then unoccupied world, and the very structure of human wants (Kuznets 1955, p. 27).

Inequality tends to fray society, reduce opportunity and innovation and produce social unrest. Picketty suggests public policy measures including wealth and property taxes to redress the situation. His point is well made. World Bank president Jim Yong Kim mentioned Picketty's findings in a speech not long after the book was published, suggesting that growing inequality affected capitalism's legitimacy:

As an economic system, global market capitalism has produced affluence and innovation. These are very good things. However, an economic system's legitimacy is also tied to its ability to make two things accessible to all: the riches it generates and the social benefits that arise from that wealth. Unfortunately, national income gains from growth tend not to be shared among a population in anything close to equal measure. In his 2014 best seller *Capital in the Twenty-First Century*, French economist Thomas Piketty showed that, in developed economies, these gains generally flow at substantially higher rates to owners than to workers. Ultimately, we want to ensure the global economic system's gains are distributed in a fashion that creates opportunity and respects human dignity (Kim 2014).

This sort of observation may be valid as far as it goes, but it is restricted in its focus to inequalities within nation-states. Yet as mentioned at the beginning of this chapter, the differences in affluence between the global West and the global South are immense. In human terms the contrast is probably far greater as almost everyone in the West enjoys standards of infrastructure, health and nutrition that are out of reach for many in the South. Further,

⁸⁵ Presumably Kuznets is referring to the UK here.

contemporary global capitalism relies on the poverty of the South to drive low cost resource extraction and the manufacture of consumer goods.

But what is the relationship between increasing inequality and humanity's impact on the environment? The relationship is positive between the two variables – and is therefore negative for the environment. Apart from the plausibility that the rich might favour nature, clean air and clean water in their own interests, concentration of wealth implies a concentration of political power. Political rules and legislation therefore tend to favour the interests of the wealthy, who are less concerned with the environmental impact of their own consumption because they are insulated from its effects. There is extensive research evidence that supports such findings, including that of the UN's Department of Economic and Social Affairs (Islam 2015). The wealthy can choose where they live, which will not be the deltas of Bangladesh or the atolls of Kiribati that will be inundated as sea levels inexorably rise. The wealthy can pay more for increasingly scarce resources to fuel their limousines and their business jets. The wealthy can heat their swimming pools and surround themselves with security walls as others might become increasingly desperate for food, shelter and fuel, as in the gated communities of South Africa, the US and Brazil. They can afford organic food that is free from contaminants as do the elite of a polluted China. The wealthy and the powerful will continue to meet together at Davos⁸⁶ to ski, to dine finely together and to reinforce their own perceptions, not to prioritise the environment.

Unless of course those with children and grandchildren may worry about the world their descendants will inherit. The media baron, Rupert Murdoch, for instance, says he worries about increasing inequality because it leads to social polarisation (Blutstein 2014), although he does not appear to have environmental concerns. Yet inequality is based on unequal benefit from the exploitation of natural resources. In Australia, for example, much wealth is concentrated amongst the owners of iron ore and coal mines and it is not that elite that is concerned about the effects of the dredging and infrastructure needed to enable its transport through the Great Barrier Reef. But to extend Murdoch's point: inequality tends to reduce societal cohesion. It is harder to debate political issues when society is polarised, and certainly more difficult to reach a consensus on what needs to be done, especially on environmental matters. The wealthy, who benefit from less regulation, tend to resist it. The impoverished, who often rely on environmental regulation to maintain their access to natural resources, may advocate more. As the World Bank notes:

environmental income shares are higher for low-income households than the rest. This is because the poor are more reliant on subsistence activities and products harvested from natural areas such as forests and lakes (World Bank 2015, p. 173).

Other interests, such as blue collar labour unions, may give priority to short-term jobs over long-term environmental protection, especially where jobs are in short supply. Growing inequality thus implies dwindling sustainability.

Better measures

Apart from Dilke's concept of wealth as free time, there may be better measures of affluence than GDP and its clones – at least some that involve environmental impact. However, this is tricky because "the ecological and social sciences have developed independently and do not

⁸⁶ Swiss village and site of the annual World Economic Forum.

combine easily” (Ostrom 2009). As yet, none has been able to establish the value of an irreplaceable songbird (Funtowicz & Ravetz 1994, p. 197).⁸⁷

Most measures that relate to sustainable affluence are either monetary or physical. Most monetary indicators are expressed as flows (such as GDP), and most physical indicators describe stocks.

There is Gross National Happiness (GNH) for example, which results from household surveys in the Kingdom of Bhutan to measure a “multidimensional” happiness index that includes “subjective well-being”. However, it is much wider than this. GNH uses 124 variables ultimately grouped into nine domains. People are considered happy when they have “sufficiency” in two thirds of the variables. The nine equally-weighted domains are: psychological well-being, health, education, culture, time use, good governance, community vitality, ecological diversity and resilience, and living standards (Ura et al 2012, pp. 1-2). Ecological diversity and resilience is based on:

Article 5 (Environment) of the Constitution of Bhutan, [whereby] every Bhutanese citizen shall ‘...contribute to the protection of the natural environment, conservation of the rich biodiversity of Bhutan and prevention of all forms of ecological degradation including noise, visual and physical pollution...’ (Ibid, p. 30).

It attempts to measure such variables as pollution and traffic congestion as well as “wildlife damage to crops”, which may appear inconsistent with environmental protection, but is important to an agricultural economy.

Under the ‘living standards’ domain, Bhutan’s GNH comes closest to ‘material well-being’ and Western notions of GDP and GNP. This includes such variables as consumption, income and expenditure, including household per capita income, assets and ‘housing conditions’ (Ibid, p. 33). Some of the results are fascinating. For example, there appears to be no relationship between per capita income and the GNH index for each district. The district with the highest per capita income is the capital (Thimphu), but the district with the highest GNH is Paro, which has considerably less per capita income. Also there is much more equality in GNH across the twenty districts than there is in per capita income.

The United Nations Development Programme’s (UNDP’s) ‘Human Development Index’ (HDI) is a related concept that, like GDP, also enables cross-country comparisons to be made. The Index is based on three factors – health, education and wealth, specifically, life expectancy at birth, mean and expected years of schooling and gross national income (GNI) per capita (\$PPP). According to the UNDP, it was created because “people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone” (UNDP 2014b). But while life expectancy is indirectly related to the environment, there is no attempt to measure environmental quality as there is with GNH.

The ‘Sarkozy Report’ (Stiglitz et al 2009) arose from the *Commission on the Measurement of Economic Performance and Social Progress* (CMEPSP). It was instigated by the former French President to assess the feasibility of alternative measurement tools to GDP, which he regarded as a distorted measure of economic and social progress. Richard Easterlin (2010, p. 1) points out that the Report’s recommendations concerning the inclusion of subjective (as well as objective) measurements of human well-being are economically “revolutionary”, almost

⁸⁷ Funtowicz & Ravetz suggest that ecological economics is a ‘post-normal science’ in which the songbird has a qualitative, beyond ordinary, value.

“heresy”, especially considering that almost all its 25 members were trained in the era of behavioural economics. With regard to the environment, however, the Report finds that:

Choices between promoting GDP and protecting the environment may be false choices, once environmental degradation is appropriately included in our measurement of economic performance (Stiglitz et al 2009, p. 7).

Further, the *Sarkozy Report* assesses the measurement of sustainability, which it regards as aspects of economic, environmental, and social dimensions of well-being over time (Ibid, p. 8). Measuring sustainability implies the measurement of wealth, or stocks of physical, natural, human and social capital that can be carried over into the future (Ibid. p. 13). It considers two approaches to measuring sustainability. One kind estimates changes in each stock separately with a view to keeping each one above its critical threshold. The other kind converts all assets into a monetary equivalent, which implies that different types of capital can be substituted for each other. However, there are problems in this latter approach, such as the lack of market values for some items as well as the validity of the assumption. As well as the songbird conundrum above, for example, Donald Worster takes exception to it in his collection of essays *The Wealth of Nature*. Rather than the market, “ecological harmony is a nonmarket value that takes a collective will to achieve” (Worster 1993, p. 133).

According to the *Sarkozy Report*, this suggests a more limited method, involving monetary measurement of stocks that already have valuation techniques available. In so doing, it should be possible to assess the economic component of sustainability, that is, whether or not countries are over-consuming their economic wealth (Stiglitz et al 2009, p. 17).

As with the *Sarkozy Report*, a key issue with assessing inclusive wealth is how to measure the value of environmental assets. Many natural assets are not traded in a market and therefore have no price. Or as the report quaintly puts it, their price is of a “non-observable nature” (UNU-IHDP & UNEP 2012, p. 18). Also, if natural assets did have a price, it would tend to rise with scarcity, so that environmental destruction would be rewarded in the index as a result of higher values for parts of the environment that remain. For example, if the value of natural forest (or ‘non-timber forest benefits’ (NTFB)) is, say, a thousand dollars per hectare, and there are a million hectares of it, then the total value of natural forest is a billion dollars. But if half of that forest area were destroyed through logging, mining and fire for example, then each remaining hectare would be worth much more, conceivably double its previous value. The total monetary value of forest assets thus remains the same, even though half has been destroyed.

Microcosms

In this light, one wonders what price could have been put on the last palm tree on Rapa Nui. While that Pacific outpost often serves as a microcosm of the whole Earth, there is conjecture about the alleged collapse of its population and its link to over-exploitation of its resources, especially tree cover. The most famous of these conjectures is in Jared Diamond’s *Collapse*, which does draw such a conclusion (Diamond 2005, p. 118). Others, however, point out that it would have been possible to know that the last tree was being destroyed - if it happened - as the whole island is visible from its centre. An alternative and plausible reason for deforestation is that the rats that arrived with the Polynesians around 1000 AD ate the seeds of the palm trees, and that during the nineteenth century its population was devastated by Western diseases and the practice of blackbirding to service the mines of Chile (Hunt & Lipo 2009, Lynas 2011).

Perhaps Nauru is a more accurate microcosm of a future degraded planet, as Naomi Klein suggests in *This Changes Everything* (2014, pp. 161-162). A lone Pacific island that was once per person the richest country in the world is now reduced to the status of a gaol for people seeking refuge in Australia. Its modern history began with its annexation by Germany in 1880 with an eye to its one main natural resource. Allocated to Australia by the 1919 Paris Peace Conference (Bashford 2012, p. 120) and made rich due to the extraction and export of its phosphate deposits,⁸⁸ those deposits are now long exhausted and much of the island is a pitted moonscape of a dug-out resource. The capital from those deposits was badly invested. Its few thousand people now appear to maintain a diet that maximises weight and diabetes. Before the arrival of refugees in detention, its only village area – a place I myself have visited several times – appeared desolate and windswept like some ghost town; its only sources of income the sale of territorial fishing rights and fees for ‘processing’ unnecessary transit visas.

Banaba, formerly *Ocean Island* and now politically part of the Republic of Kiribati in the central Pacific, is a variant of the Nauru story. Like Nauru it was extensively mined for phosphate, but was depopulated during World War II due to massacre by the Japanese and forcible relocation by the British (Hindmarsh 2002, pp. 9-10). Ultimately a trust fund of \$10 million was established sourced from its profits, prior to Independence in the 1970s. That fund has been hardly touched since its establishment and now totals about \$650 million, a vast sum representing several thousand dollars for each inhabitant of the republic,⁸⁹ let alone the island, making the republic debt free. However, the ownership of the fund is now a matter of dispute between the Banaban diaspora, who live mainly in Fiji where they were relocated by the British, and the government of Kiribati, that incorporates the island as part of its territory. The population of the island itself is now only about 300 and it is almost completely isolated as there is no regular transport link between the island and anywhere else, either by sea or air. Thus even though the (natural) capital of the island was at least partly converted to the (financial) capital of the trust fund, neither the island itself, its inhabitants nor their descendants have benefited to any degree. The island remains derelict, its inhabitants are reduced to subsistence and the Fijian diaspora face an uncertain future.

Makatea in French Polynesia was the third Pacific phosphate island, mined between 1917 and 1964. Like its more westerly neighbours it too now lies ravaged and desolate.

In the Indian Ocean, Christmas Island’s phosphate deposits were exhausted during the late twentieth century and grandiose proposals for an international casino and a spaceport have yet to eventuate. Instead, like Nauru, its main industry is now as detention centre for asylum seekers to Australia. Its namesake, Kiritimati⁹⁰ Island, the world’s largest coral atoll, located in the Central Pacific, escaped phosphate mining only to become a site for nuclear testing by the US and UK during the 1950s and 1960s.

Whether or not these six examples foretell a global calamity, they at least demonstrate the importance of maintaining, or at least offsetting the loss of natural capital. The possession of a considerable natural resource can be a curse as much as a blessing.

⁸⁸ Nauru’s phosphate rock was highly concentrated – up to 39 per cent usable phosphate (McKelvey 1967).

⁸⁹ About \$6500. The total Kiribati population is about 100,000.

⁹⁰ Pronounced similarly – the ‘ti’ is pronounced as an ‘s’ in Gilbertese, which uses only 13 letters.

Inclusive wealth

The value of Rapa Nui's last palm tree was never quantified, which may be connected to its demise. Achim Steiner⁹¹, writing in the United Nations University-United Nations Environment Program (UNU-UNEP) *Inclusive Wealth Report 2012*, points out that the very lack of measurement of nature contributes to environmental damage:

There has for some time been a shared recognition that conventional indicators such as gross domestic product (GDP) or the Human Development Index (HDI) are failing to capture the full wealth of a country. These limitations may be in part fuelling environmental decline and degradation because changes in natural or "nature-based" assets are not factored into national accounts, rendering those accounts less useful as an indicator of changes in human well-being (UNU-IHDP & UNEP 2012, xi).

The *Inclusive Wealth Report* begins to rectify this lack of measurement and resultant focus. It attempts to construct an 'inclusive wealth index' (IWI) that shows how the full range of productive wealth is changing over time. The basis of 'inclusive wealth', according to the Report, is three types of productive assets – capital, human and natural. So not only does it broaden the accountant's view of wealth to include both human and natural capital (the environment), but it also focuses on the stock (wealth) rather than the flow (income or production) of GDP-style accounting, as recommended by the Sarkozy report. This is similar in concept to the adjusted net savings (ANS) approach (World Bank 2013).

Therefore, importantly, positive growth rates in 'inclusive wealth' represent sustainability, because the total productive base is not eroding. As a result, the asset base can continue to produce similar or better levels of output for consumption by future generations (UNU-IHDP & UNEP 2012, p. 11). By contrast, positive growth rates in GDP accounting often correlate with loss of sustainability because they are based on the exploitation of limited resources. The HDI, because it includes GNI per person as one component, is similarly limited, although to a lesser degree.

The *Inclusive Wealth Report* (IWR 2014) shows how natural resources, along with human and productive capital, can be monitored through calculation of the Index over time. However, the representation of the three sub-categories as well as the total wealth index in the report facilitates monitoring of each separately and shows how they are inter-related. For example, there are five countries that had reductions in their IWI over the period 1990-2008, (Colombia, Nigeria, Russia, Saudi Arabia, and Venezuela) but had an increase in GDP per capita. Most of these countries were drawing down their large oil reserves without sufficient compensatory increases to their produced and human capital bases. Thus the negative IWI growth rates "suggest an unsustainable track and most of the GDP growth has come at the expense of the natural capital base" (UNEP 2014, p. 43).

The contrast between IWI change and GDP growth becomes clearer in chapter 4 of the Report, where each of the contiguous states of the US are compared for both measures. In summary, states with high GDP growth tend to have much lower rates of inclusive wealth growth, again suggesting that GDP is generated by running down capital stocks (UNU-IHDP & UNEP 2012, xxiv).

There are three main problems with GDP. First, well-being is associated with income alone, which may be a necessary condition for well-being, but not a sufficient one. 'Peace of mind',

⁹¹ Under Secretary-General of the United Nations Environment Program 2006-2016.

belonging to a community, safety and good health also support well-being. Second, GDP ignores the environmental externalities that result from the production process or the scarcity of dwindling natural resources, which are often public goods with no market prices. Third, GDP represents flows over a short time period, but does not provide information on the state of the capital stocks necessary to generate the income measured, or if they are sufficient for future generations. It masks production based on an unsustainable exploitation of natural resources.

The key variables used to measure inclusive wealth are shown in figure 23 below. Of the 54 categories; more than half relate to natural capital (A-E) and how it is adjusted. The reason for including 'population' under 'produced capital' is not clear, however, given that it is directly relevant to 'human capital', as is the separate category of 'health capital'.

Figure 23. Variables used to measure inclusive wealth.

Natural capital	Human capital
<i>A. Fossil fuels</i>	Population by age and gender
Reserves	Mortality probability by age and gender
Production	Discount rate
Prices	Employment
Rental rate	Educational attainment
	Employment compensation
<i>B. Minerals</i>	Labour force by age and gender
Reserves	
Production	Produced capital
Prices	Investment
Rental rate	Depreciation rate
	Assets lifetime
<i>C. Forest resources</i>	Output growth
Forest stocks	Population
Forest stock commercially available	Productivity
Wood production	
Value of wood production	Health capital
Rental rate	Population by age
Forest area	Probability of dying by age
Value of non-timber forest benefits (NTFB)	Value of statistical life
Percentage of forest area used to extract NTFB	Discount rate
Discount rate	
<i>D. Agricultural land</i>	Adjustments in IWI
Quantity of crops produced	<i>A. Total factor productivity</i>
Rental rate	Technological change
Price of crops produced	
Harvested area in crops	<i>B. Carbon damages</i>
Permanent cropland area	Carbon emission
Permanent pastureland area	Carbon price
	Climate change impacts
	GDP
	Discount rate
<i>E. Fisheries</i>	
Fishery stocks	<i>C. Oil capital gains</i>
Value of capture fishery	Reserves
Quantity of capture fishery	Oil production
Rental rate	Oil consumption
	Prices
	Rental rate

Source: Inclusive Wealth Report, UNU-IHDP & UNEP 2012, p. 31.

As shown above, natural capital assets are grouped as fossil fuels, minerals, forest resources, agricultural land, and fisheries. The IWI attempts to measure the value of these natural assets through the technique of 'shadow pricing', whereby a monetary value is assigned to the asset and compared with the stock of the asset at a later time. For non-renewable resources such as oil, the stock diminishes according to how much has been extracted during the period. The shadow price of each unit is the market price minus the marginal cost of its extraction⁹² (UNU-IHDP & UNEP 2012, p. 53).

There are also 'externalities' involved. Because using the oil also damages the environment through oil spills and carbon dioxide accumulation for example, the total value of the asset must also be reduced to account for the cost of rectifying the damage. These 'externalities' are listed in the section '*Adjustments in IWI*' (A-C) in figure 23 above. Some are positive adjustments, such as productivity increases arising from new technology and the discovery of new oil reserves, while some, such as *carbon damages* of fossil fuels are negative. While parts of the index could be calculated differently – oil and mineral reserves could be simply diminished by extraction and increased by discovery of new deposits for example – the index is reasonably comprehensive without being overly detailed.

The IWR points out that its '*inclusive wealth*' is different from the '*comprehensive wealth*' concept that the World Bank developed in the late 1990s. Because *inclusive wealth* is the social worth of an economy's capital asset base, crucially its accounts do not assume sustainability of consumption. Changes in wealth are measured directly from the changes in the asset base. '*Comprehensive wealth*', however, assumes that wealth is the discounted flow of consumption and the Bank's formulation "inadvertently assumes that consumption is always on a sustainable path" (Ibid, p. 24). On the other hand, according to the World Bank itself, its *comprehensive wealth* allows changes in wealth "to measure the sustainability of development" (World Bank 2011, p. 4). The IWR claim about the Bank may be debatable, but the single index it produces is an outstanding and valuable feature.

Importantly for this dissertation, however, the IWR also says that:

population has to be acknowledged as a critical factor in sustainability. Although the comprehensive wealth accounts do provide per capita figures, the underlying assumption is that population is kept constant. In the case of the inclusive wealth estimates, population growth is intrinsically captured in the framework and the growth rate has been factored in the analysis. Not surprisingly, results show significant differences between estimates with and without population growth (UNU-IHDP & UNEP 2012, p. 23).

But while the *Inclusive Wealth Index* has advantages as a measure of well-being and sustainability, it also has several weaknesses.⁹³ Most importantly, its breadth of data is limited.

⁹² Also known as the 'rental value'.

⁹³ The report suffers from poor editing and, for the English version at least, it is obvious that many of the authors are not writing in their mother tongue or that they are translations. Also labelling is sometimes incoherent. In appendix 1 for example, it is difficult to identify which sub-index is which because the key does not correspond to the three categories shown. Some of the defects may well be due to coordination difficulties due to the scope of the report and the nature of the two organisations that produced it. The UNEP headquarters are in Nairobi, whereas the United Nations University operates from Bonn. Further, the small UNEP tends to have less clout than the larger established UN agencies and institutions such as the World Bank.

While they are reasonably representative, it covers only twenty countries,⁹⁴ and only four of them in relation to fisheries due to lack of comparable data for the rest. It also covers only ten types of minerals,⁹⁵ albeit generally the more valuable. Also, the obscure language used may explain why the IWI has failed to become more widely used outside of ecological economics, as in the “non-observable nature” of market prices terminology mentioned earlier (Ibid, p. 18).

However, the strength of the IWI is the singular clarity it brings to sustainability. None of its weaknesses are insurmountable, but if the IWI is to gain the wider acceptance of measures such as GDP, its incorporation into broader programs and the securing of institutional political clout are indicated.

Footprint

If the IWI has yet failed to gain much political traction, the now-familiar concept of the *ecological footprint* (EF), is an alternative that has several advantages. The EF is a relatively simple aggregate indicator, developed by Wackernagel & Rees in 1996. It calculates the productive land area needed to sustain the consumption and assimilate the waste generated by populations. It is expressed as the land area required to meet consumption levels and can be compared to a country or region’s natural carrying capacity. If the EF exceeds the natural carrying capacity, then the population is living beyond the carrying capacity of the land they occupy. It must be either depleting its own natural resources unsustainably, or living off the natural capital of other nations or regions. Of course globally, apart from fanciful ideas of comet and asteroid mining, the latter option is not available. If the global EF is greater than the carrying capacity of the Earth, then it is unsustainable. Wackernagel has calculated estimates of the EF for 52 countries or 80 per cent of the world’s population (Anielski 2001, p. 7).

Other indicators

Anielski mentions several other significant attempts to measure sustainable well-being in line with Kuznet’s earlier dashed hopes in constructing the national accounts for GDP. These include the *Index of Sustainable Economic Welfare* (ISEW) developed by Herman Daly, John Cobb Jr and Clifford Cobb in the late 1980s. It is a flow measure, based on consumption expenditure as for GDP, but it adds benefits such as unpaid work. It then deducts social costs such as crime and further deducts environmental costs such as pollution and depletion of non-renewable energy. The *Genuine Progress Indicator* (GPI) is a modification of the ISEW concept that originated in the US in the 1990s by Cobb, further developed by Clive Hamilton in Australia (Hamilton & Denniss 2000), and elaborated in Nova Scotia, Canada. There is also the ‘*dashboard of sustainability*’, developed by the International Institute for Sustainable Development (IISD), which aggregates the three clusters – economic, environmental and social – as dials on a car or aeroplane dashboard (Anielski 2001, p. 6). In this respect, it has been observed that “the idiot lights on our planet’s dashboard are flashing” yet we continue with business as usual (Sutton & Costanza 2015).

Prompted by the activity surrounding the SDGs, the fifth OECD World Forum held in Guadalajara, Mexico, centered on the limitations of using GDP as a measure of progress and discussing alternatives. Within its 34 developed-country members there is increasing

⁹⁴ Australia, Brazil, Canada, Chile, China, Colombia, Ecuador, France, Germany, India, Japan, Kenya, Nigeria, Norway, the Russian Federation, Saudi Arabia, South Africa, United Kingdom, the United States and Venezuela

⁹⁵ Bauxite, copper, gold, iron, lead, nickel, phosphate, silver, tin, and zinc.

acknowledgment that well-being does not automatically flow from economic growth and that the natural environment must be preserved (Shaw 2015, paras 3-7).

Environmental Kuznets curve

The environmental Kuznets curve (EKC) is a construct named for him, rather than ascribed to him, that emerged during the 1990s (Stern 2004, p. 1420) and which crucially addresses the relationship between affluence and environmental damage. The EKC concept says that, like Kuznet's inequality curve, environmental damage will at first rise with economic development, then peak at a certain level of income, and then decline again as the economy matures into a 'developed' state. As Grossman & Krueger (1995 p. 353) put it in their influential study *Economic Growth and the Environment*:

Will continued economic growth bring ever-greater harm to the Earth's environment? Or do increases in income and wealth sow the seeds for the amelioration of ecological problems? The answers to these questions are critical for the design of appropriate development strategies for lesser-developed countries. Exhaustible and renewable natural resources serve as inputs into the production of many goods and services. If the composition of output and the methods of production were immutable, then damage to the environment would be inextricably linked to the scale of global economic activity.

The study involved matching national-level GDP with local air and water quality data (urban air pollution, oxygen levels, fecal contamination and heavy metal contamination of river basins) in representative urban areas of 42 different countries between 1977 and 1988. Grossman & Krueger confirm and extend earlier findings, especially including those of the World Bank (1992, p. 11). They say that:

Instead we find that while increases in GDP may be associated with worsening environmental conditions in very poor countries, air and water quality appear to benefit from economic growth once some critical level of income has been reached (Grossman & Krueger 1995, p. 370).

That critical level of income varies again by indicator or pollutant. However, it averages about USD8000 per person per year in 1985 dollars, or around USD14,000 in 2015 terms – coincidentally about the mean global GDP per person. Thus the underlying concept of the EKC has significant support.

However not everyone favours growth in whatever form. For example, the former Professor of Economics at the London School of Economics, EJ Mishan, lamented that:

The 'Age of Abundance', it transpires, is abundant with pre-packaged and chemically processed foodstuffs, with plastic knick-knacks, with plug-in electric gadgets and stereo equipment. And a part of the price that people in the West pay for this unending procession of shiny assembly-line products is the concomitant loss of those now rarer things that once imparted zest and gratification – the loss of individuality, uniqueness and flavour; the loss of craftsmanship, local variety and richness; the loss of intimacy and atmosphere, of eccentricity and character (Mishan 1992 [1967], pp. 125-126).

Similar attitudes are evident in Kenneth Galbraith (*The Affluent Society* 1958) and Hamilton & Denniss (*Affluenza* 2005).

More specifically, Grossman & Krueger (1995) do not address two critical findings of the 1992 World Bank report on economic development and the environment.⁹⁶ While the Bank found that increasing levels of income were associated with better access to clean water and sanitation, as well as ultimately to cleaner air, the Bank also found that *municipal waste* rose dramatically with income per person as did *carbon dioxide* emissions per person.⁹⁷ Municipal waste is of course a major issue. However it is not an issue that is insurmountable: there is plenty of scope for profit in its minimisation, and especially in its collection and treatment, as the recent fortunes of Veolia, the French multinational, demonstrate.⁹⁸ Further, the impact of carbon dioxide emissions on climate change is now of course probably the most important global issue. In 1992 the Bank suggested several policy measures aimed at improving the general situation, especially including the reduction of fuel and energy subsidies, which they say would cut emissions substantially (World Bank 1992, p. 12). Today it is clear that much more is required (IPCC 2014a).

Consumption and capitalism

Aside from the issue of pollution and environmental degradation, the Nobel laureate astrophysicist, Brian Schmidt, in arguing for scientists to have formal input into science policy, has summed up the situation of affluence that confronts us. Affluence depends on the availability of energy, but using readily available energy has negative consequences:

...the great world challenge is figuring out to transition to an Earth of ten billion people who all want what we have, which turns out to be seven times what the average person has right now and 80 times more than the median person has. My guess is that we rich are not keen to drop our standard of living, so we need to raise the standards of everyone else...prosperity correlates better worldwide with the amount of energy consumed...we already have a ready supply – coal and gas – but the problem is that it leads to climate change...the greatest scientific challenge for the world is figuring out how to use technology to develop the energy necessary to sustain in relative harmony the needs of ten billion people (Schmidt 2014).

There are other perspectives. For example, apart from Fowler & Hobbs' (2003, p. 2579) finding that human consumption differs from other species by orders of magnitude, Vitousek et al had earlier assessed the total use of the world's food supply by humans, then numbering about five billion. They found that humans were appropriating 40 per cent of that available through photosynthesis on land, crowding out that available to the other "5 - 30 million animal species on Earth" (Vitousek et al 1986, p. 368). A more recent study found that humans consume 25 per cent of the production of all land plants, nevertheless still twice the rate of replacement (Charlton 2011, p. 6)

The contemporary Marxist perspective is that there is an ecological contradiction at the heart of capitalism (Foster 2002, para. 1). A particularly jaundiced view of this is from the US political scientist Michael Parenti in *Against Empire* (1995):

⁹⁶ World Bank World Development Report 1992: Development and the Environment.

⁹⁷ Grossman & Krueger do not directly state why these measures were not included, but rather imply that the data sets they analysed did not include them.

⁹⁸ *Veolia Environment S.A.*, formerly *Vivendi*, formerly *Compagnie Générale des Eaux* (CGE), or the Universal Water Company, was originally set up in Lyons by Napoleon III in the mid 19th century. According to its website, in 2012 it had more than 300,000 employees in 48 countries and revenue of nearly 30 billion euros.

The essence of capitalism is to turn nature into commodities and commodities into capital. The live green Earth is transformed into dead gold bricks, with luxury items for the few and toxic slag heaps for the many. The glittering mansion overlooks a vast sprawl of shanty towns, wherein a desperate, demoralised humanity is kept in line with drugs, television, and armed force.

The psychologist, Oliver James, in *The Selfish Capitalist: Origins of Affluenza* tends to support such a view. Writing on the brink of the Great Recession, he finds that misery and distress especially in the English-speaking West has become widespread since the 1970s as inequality has increased and the wealth of a tiny minority has ballooned. He ascribes this situation to the extreme neoliberal capitalism that afflicts the Anglosphere and the inequalities it has produced. Such a political economy is not as entrenched in other cultures (James 2008). Devin Nordberg (2002, p. 15) takes a wider view, writing that the issue is based on “serious, structural injustices on a global scale”. Sustainable futures should not be built on “technical imperatives”, but rather “on political values”, he says. While hungry people will always support growth in the hope “it will relieve their misery”, “as long as production occurs for profit rather than for human needs, growth will continue”, irrespective of any human values of sufficiency.

The Australian philosopher Clive Hamilton believes that there are forces that tell us as individuals that it is our fault and that it is up to each of us to save the environment through our own personal habits of consumption. But the forces that produce unsustainability are much wider and need to be approached socially and politically:

The fact is that we are not personally responsible for the ecological dangers we face. The structure of our society is responsible⁹⁹ and we are responsible as citizens for our failure to insist that the necessary measures are taken. In the end we cannot consume our way to sustainability (Hamilton 2005).

Thus affluence – ultimately material wealth rather than happiness – is measured by both human production and human consumption. It is created originally from nature using human labour and technologies that define both an age and our relationship with the environment. Affluence is accumulated and distributed increasingly unevenly both within and between countries and, because it tends to deplete stored sources of energy, it will have to become less dependent on fossil sources (as well as scarce non-renewables) if its distribution is to be made more equal. Its effects on species and their habitats have been highly destructive, especially in recent decades as consumption is amplified through pervasive technologies and population increase.

To the extent that economics’ worship at the singular altar of growth is a barrier to sustainability in the developed world, it is trumped by the basic need for survival. A better economics would emphasise sustainability. ‘Growth’ would emphasise deep quality, not brute quantity. More could be better off if durability, energy conservation and zero waste were revered more than obsolescence, extravagance and effluent.

⁹⁹ Even at neighbourhood level, communal societies with shared technologies such as laundries tend to consume less per person than individualist societies where each household has a washing machine, for example. Also, urban densities may dictate low-consumption public transport compared with high-consumption private cars in suburban areas.

Lip service

The World Bank's 1992 World Development Report *Development and the Environment*, showed promise in its awareness and policy prescriptions for sustainability:

The main message of the Report is the need to integrate environmental considerations into development policymaking. The value of the environment has been underestimated for too long, resulting in damage to human health, reduced productivity, and the undermining of future development prospects (WDR 1992, p. iii).

But despite the positive developments of the 1990s, the measurement options and analyses produced since, and the climate imperatives of the early twenty-first century, recent World Bank reports indicate that sustainability has yet to be mainstreamed within the Bank's collective consciousness. The issue of environmental impact is almost entirely ignored in its 2015 report, *A Measured Approach to Ending Poverty and Boosting Shared Prosperity*, for example.

The opening statement of the report mentions that prosperity must “fully account for environmental degradation and natural resource depletion” (World Bank 2015a, p. 1) and later in a faint echo of Brundtland, stresses that “the path toward [growth and prosperity] must be environmentally, socially, and economically sustainable over time” (Ibid, p. 14). However, the document is otherwise all about growth. Apart from the risk of climate change and access to natural resources treated cursorily in chapter 4 – and the back cover declaration that it is printed on environmentally-friendly recycled paper – these examples are the only times the environment is mentioned in the entire 280-page report. Thus for this major Bank report, the issue is still how to get economic growth to reduce poverty, while it pays lip service to the environment in the face of overwhelming concern about how that growth is achieved. The Bank's 2017 *Atlas of Sustainable Development Goals* does mention decoupling environmental degradation¹⁰⁰ from economic growth, which is one of the 169 SDG targets. It usefully proposes how it may be measured and ranks countries by performance. However, it shows the same target as ‘8f’ in the main text (World Bank 2017a, p. 48) and ‘8.4’ in the appended list of goals and targets (Ibid, p. 118), which tends to show it is not fully in focus.

The IMF also appears to lack focus on environmental sustainability in its endorsement of growth. While in a particular statement about the SDGs, there is a mention that the Fund is “deepening policy advice on aspects of inclusion and environmental sustainability and bringing this advice to its operational work” (IMF 2017a), this is the last and least specific of several initiatives outlined. Its World Economic Outlook (IMF 2017b) also mentions the term ‘sustainable’ – but only in the context of debt repayment.

However, where economic growth has been spectacularly successful in raising affluence, yet disastrous in environmental terms, there is renewed emphasis on environmentally sustainable economic growth (Liu 2010, Zhang 2012, Cohen 2016). But this is because pollution in China is so pervasive that it is impossible to ignore, including the political consequences of failing to address it. Elsewhere, the environmental price of growth may be more conveniently ignored because it is out of sight. Few governments – and major international institutions like the Bank

¹⁰⁰ “Degradation includes the costs of greenhouse gas emissions from fossil fuels, agriculture, forestry, and land use change; the harvest of forest timber resources beyond sustainable rates; and reduced labour output due to premature mortality caused by exposure to environmental risk factors such as air pollution, unsafe water and sanitation, and harmful substances in the workplace” (World Bank 2017a, p. 48).

and the Fund – risk dilution of the ‘growth and jobs’ paradigm where political success demands it. Governing elites tend to avoid complicating the message. Economic growth delivers prosperity. Any environmental nuance that takes nature into account threatens political defeat.

Species perspective

As José Mujica, then President of Uruguay, said to the UN General Assembly on 28 September 2013, we tend to think and reason as individuals or as countries, but “poverty could be eliminated from the planet if we could begin to reason as a species. The current form of civilisation cannot be maintained. We must understand that we are a species and we must govern ourselves as a species” (Mujica 2013). Pope Francis echoes this in his encyclical *Laudato si’*:

We need to strengthen the conviction that we are one single human family. There are no frontiers or barriers, political or social, behind which we can hide, still less is there room for the globalisation of indifference (Pope Francis 2015, s.52).

Mujica occupied no palace as president of his country. At his insistence, his dwelling was little more than a shack. It did, however, have a Victorian water closet; at least in this small way he was more affluent than Suleiman the Magnificent.

Chapter 6. Technology

All history is relevant, but the history of technology is the most relevant

– Melvin Kranzberg 1986¹⁰¹

Humanity has an ancient and intense relationship with technology. Such is our mutual embrace that it seems unique to our species and is definitive of us. But in its relationship to sustainability, contradictions are apparent. It is technology that has led to resource depletion and degradation of the environment, whereas it is in technology that there lies hope for a more sustainable future. Technology has enabled the creation of modernity that briefly shields our species from its long-term consequences. It has both allowed us to become more crowded and consume ever more, yet it may also enable us to become happily fewer and for each of us to tread more lightly on the planet. Technology is associated with industrial pollution, but at the same time it can help reduce pollution. Its impact differs according to the nature of technology and how it is deployed. As Kranzberg also said, “technology is neither good nor bad; nor is it neutral” (Kranzberg 1986, p. 545).¹⁰²

There is a yawning chasm between extreme views of the relationship concerning technology and humanity, both positive and negative polar opposites. How that void is bridged may well determine our continued existence as a species, as well as the fate of the other life forms that cohabit the Earth with us. This chapter assesses key approaches to technology and sustainability and their development over the length of human history, including issues of economics, energy and ethics. It concludes with a summary of the present relationships in which technology is bound.

Warnings

Warnings about technology include the wings of Icarus that enabled him to fly to the heavens but brought about his death. Significantly the wings were built for him by his father Daedalus, the artisan who had also constructed the labyrinth that imprisoned the Minotaur. Daedalus’ creation of a means to achieve the god-like power of flight has destructive consequences, and the gift of this technology results in a double disaster: the death of a son and a father’s grief. Similarly, the titan Prometheus stole fire to benefit the humanity he had created, and was condemned to eternal torture for his efforts by Zeus, because it was a challenge to the power of the gods. One version of the myth includes the vesting of the troubles of an archetypical Pandora onto humanity by an angered Zeus: “From her the tribe of women comes - for men a grievous bane” (Hesiod 2010 [c.800BC], 590). Hephaestus was the god associated with the technologies of the forge, but he was deformed due to poisoning from the arsenic used in bronze metallurgies in ancient times.

During the Middle Ages mechanical technologies involving clockwork and other means spread through Europe from the East. They were regarded as magical, much as nature was regarded as a powerful entity to be feared rather than understood. According to the historian E.R. Truitt (2015), eventually around the seventeenth century these mechanical wonders were generally regarded as operating according to natural laws, instead of by magic. At about the same time, nature was further diminished by Newton’s *Principia* (1952 [1686]), a work made possible by

¹⁰¹ This is the historian Kranzberg’s fifth law of technology. His 1985 address listed six in total.

¹⁰² This is Kranzberg’s first law.

optical technologies.¹⁰³ Rather than a powerful entity, 'nature' became abstract, predictable and subject to law much like a mechanical clock.

During the same era the morality tale of a Dr Faustus, who sold his soul to the Devil for the chance to know everything and to command nature, was widespread throughout northern Europe. This fable was later disseminated by the technology of print and became available to the English playwright, Christopher Marlowe who wrote it as a play in 1602. Faustus' authority over nature was;

To do whatever Faustus shall command,
Be it to make the moon drop from her sphere,
Or the ocean to overwhelm the world (Marlowe 2009 [1604], p. 23).

Two hundred years later at the beginning of the nineteenth century, Johan von Goethe's *Faust* was published on a similar theme.

Still during the early Industrial Revolution, Mary Shelley's fear of technology was evident in her immensely popular novel *Frankenstein: The Modern Prometheus* (1818),¹⁰⁴ which involved the creation of life through technology, as the titan had created humanity. In the introduction to the 1831 edition, Shelley mentions Erasmus Darwin, the grandfather of Charles, and Luigi Galvani as sources of inspiration. Darwin had earlier written of experiments concerning life developing from apparently lifeless forms and Galvani's theories of animal electricity had already famously been applied to the corpse of a murderer (Simili 2014). Dr Frankenstein's god-like creation of life was a warning about new technology, but technology and humanity were linked to total catastrophe by Shelley in her later book, *The Last Man*, published in 1826. In the book, at the end of the twenty-first century, masculine belief in technological mastery over nature is proved false when rapid climate change, famine and finally plague exterminate humanity on Earth (Shelley 1997 [1826]).

Apocalyptic visions of the future based on technological catastrophe are now commonplace, such as Margaret Atwood's 2003, *Oryx and Crake* in which a genetically modified virus wipes out the entire population. Earlier similar works include René Barjavel's 1943 novel *Ravage*, in which a future France is devastated by the sudden failure of electricity as well as E. M. Forster's 1909 novella *The Machine Stops*, in which humanity is entirely dependent on a god-like machine that deteriorates and eventually stops, ending the lives of everyone.

Less cataclysmic but more poignant is Hans Christian Andersen's 1843 tale *The Nightingale*¹⁰⁵ in which the emperor of China banishes his living nightingale in preference to a bejewelled mechanical bird – "As soon as the artificial bird was wound up, it could sing like the real one, and could move its tail up and down, which sparkled with silver and gold" — sent to him by the emperor of Japan (Andersen 1843). The emperor is, however, overwhelmed with despair when the mechanical nightingale can no longer sing due to a broken spring. Nearing death from his misery, finally the emperor hears the song of the living nightingale and is revived

¹⁰³ Optical technologies included lens making and the production of parabolic mirrors. Newton himself designed and constructed an improved telescope using both these techniques.

¹⁰⁴ The book has been reprinted numerous times, including in French as early as 1821, and it has inspired many plays and films.

¹⁰⁵ The story was also the basis for Stravinsky's 1916 *Le Chant du Rossignol*.

(cited in Johnson 1990, p. 71).¹⁰⁶ Mechanical technologies can be alluring but are ultimately only imperfect imitations of nature.

From a subtler perspective, German existentialist philosopher Martin Heidegger was a major twentieth century critic of technology. In *The Question Concerning Technology* (1953), Heidegger said that the modern technological "mode of being" saw the natural world only as a resource to be exploited, as a means to an end. Heidegger illustrated this with what many would now regard as a rather benign form of technology - a hydroelectric plant on the Rhine – but which changed the river from an unspoiled natural wonder to merely a power supply (Heidegger 1953, p. 321). Thus technology is not just a collection of tools, but rather a way of understanding the world, which is both "instrumental and grotesque" (Wheeler 2013). Whether Heidegger would have preferred his electricity to be supplied from a coal-fired power station is not made clear in the essay. Yet his insight remains: existing technologies, especially those that derive energy from natural resources, reduce nature to that singular measure. In this sense, humanity too is diminished by our technologies.

Technology equates to pollution in some views. As well as the poisoning of Hephaestian bronze workers, there is evidence of lead pollution from mining in ancient times (Hong et al 1994) and atmospheric pollution from fires and furnaces has been a problem since at least the Middle Ages.¹⁰⁷ Before the Second World War, "smoke, sewage, and soot were the main environmental concerns" (Heaton et al. 1991, p. 5).

However, something changed after 1945 and it concerned new technologies. There was the new threat of radiation and radioactive waste from nuclear technology, as well as concern about the new synthetic chemical technologies highlighted by Carson's *Silent Spring* (1962). Barry Commoner, "the Paul Revere of ecology" in *The Closing Circle* (1971) identified the "technological suicide"¹⁰⁸ caused by the scale and nature of pollution that had engulfed the US, also since the 1940s. Commoner showed how these unregulated new technologies (especially synthetic organic chemicals from plastics, detergents and biocides) caused great harm to the ecosystem, at a rate far greater than economic growth:

Postwar technological transformation of the US economy has produced not only the much heralded 126 per cent rise in GNP, but also at a rate about ten times faster than the growth of GNP, the rising levels of environmental pollution (Commoner 1971, p. 146).

Commoner engaged in intense public debate with population alarmists such as Paul Erlich, arguing that humanity's negative impact on the planet was largely due to these uncontrolled new technologies rather than due to too many people who consumed too much. In 1974 Ariyoshi Sawako, published the first instalment of the novel *Fukugo osen (Compound Pollution)*, which tapped into deep concerns about the effects of pesticides and organic chemicals in Japan. The destruction of the Earth's protective ozone layer by chlorofluorocarbons from refrigerants and spray can propellants was identified in the 1970s, as was the resulting enlargement of the 'ozone hole' over the Antarctic.

¹⁰⁶ Johnson also points out that the industrialisation of Japan during the nineteenth century was a conscious top-down political response to the technological imperialism of the West, rather than the more organic economic and technological processes of Britain and the US (Ibid, p. 72).

¹⁰⁷ Burning 'sea coal' was prohibited in London in 1306 because it emitted too much smoke.

¹⁰⁸ Quotations are from the 1972 edition book jacket.

Positives

More positively, Carson's book led to the banning of DDT¹⁰⁹ and to far greater scrutiny of the effect of pesticides on the environment. Commoner contributed to an awareness of ecosystems, while Sawako's work led to organised consumer demand for organic products in Japan (Moen 1997). Protecting the ozone layer was effected through the world's first universally signed treaties – the *Vienna Convention for the Protection of the Ozone Layer* (1985) and its *Montreal protocol* (1997) – both endorsed by 197 states including the European Union.

Far earlier, but decisively, the relationship of technology to humanity has been linked to ultimate survival by recent science. In *When the Sea Saved Humanity*, anthropologist Curtis Marean (2010) explains how the development of advanced composite stone tools, including “sophisticated implements such as microblades” involving heat-treated quartz to make it easier to shape and attached to wooden shafts to form spears, was a factor that enabled the last remnants of humanity to stay alive during an Ice Age around 150,000 years ago¹¹⁰ in southern Africa. Humanity, then reduced to a total of only a few hundred breeding individuals literally clinging to the edge of the continent, would likely have become extinct without these technologies that enabled successful fishing when there was no game and little vegetation. If so, we now owe our very existence to that relationship – all of us are descended from those lucky few.

Nevertheless, Gore (2013, p. 357) asserts that this critical time for humanity before migration from Africa occurred, was one of three occasions when humanity did not appear sustainable. The other two were in the 1960s when nuclear war between the US and the USSR appeared imminent, and now when we are changing the biosphere irreversibly to the detriment of ourselves as well as other species. In the first case technology is positive. But the latter two cases show that complex technologies can have profoundly negative effects.

Nevertheless, and more generally, technology as a positive force is defined by the future. The future appears to attract technology as iron to a magnet, because the future is all about technology; it represents the notion of human progress. Without technological change the future would consist of successive generational replacement and little else. In prehistoric times there might be tomorrow or even next winter, but there was no future.

The future, especially a better future, only became possible with the development of complex technologies. How those technologies might be applied became the stuff of science fiction. For example, Jules Verne anticipated submarines (in *Twenty Thousand Leagues Under the Sea*) and spaceflight (*From the Earth to the Moon*) during the nineteenth century. The Internet, or at least part of it, was invented in fiction long before it existed in reality. H.G. Wells publicised the idea of a ‘world brain’ or permanent encyclopedia using microfilm in 1936, so that anyone, anywhere could examine any book or document that had been assembled by the encyclopedia (Wells 1938). Arthur Clarke presciently suggested in 1962 that this encyclopedia or library could be accessed by personal computers by the year 2000, but that its extension to involve artificial intelligence might take another century.

Isaac Asimov in his *Foundation* series, beginning in the 1940s, conceived of a foundation located at the end of the galaxy. This foundation enabled human knowledge to be preserved

¹⁰⁹ At least in the West. India, however, continued its use as a malaria control agent (Kranzberg 1986, p. 546).

¹¹⁰ According to Marean, about 195,000 years ago the planet entered a long glacial stage known as Marine Isotope Stage 6 (MIS6) that lasted until about 123,000 years ago.

and advanced during a period of galactic chaos, which was predicted by the invention of a mathematical sociology, *psychohistory*. The foundation's technology is regarded by its neighbouring primitive planets as a form of religious magic, which anticipated Arthur Clarke's famed third law: "any sufficiently advanced technology is indistinguishable from magic" (Clarke 1962, p. 14). Clarke's later work, *Imperial Earth* predicts desktop "communications consoles" with screens and keyboards as well as "minisec" mobile computing devices that can communicate with the consoles, albeit only within visual proximity (Clarke 1975, pp. 126-128). And the once ubiquitous Samsung flip-phone of the early twenty-first century was reputedly modelled on the 'Beam me up Scotty' communicator device of the 1960s *Star Trek* television series, set in the twenty-third century.

Meanings

The word 'technology' was first recorded in English in the early 1600s, meaning "a discourse or treatise on an art or the arts," from the Greek 'tekhnologia' - the "systematic treatment of an art, craft, or technique". The meaning "study of mechanical and industrial arts" such as "spinning, metal-working, or brewing" was first recorded in the mid 1800s. Its former component, 'techno' is from the Greek 'tekhne' "art, skill, craft in work; method, system, an art, a system or method of making or doing," originally related to weaving. Its latter component '-logy' means "a speaking, discourse, treatise, doctrine, theory, science," from the Greek '-logia' from root of legein "to speak" ('Technology' 2014).

However, the contemporary meaning of the word 'technology' is much broader. As a result of the so-called 'second Industrial Revolution' during the latter part of the nineteenth and early twentieth centuries, when steel making, electrification, the telegraph and the production line defined a new era, the term came to mean both the study of the useful arts and crafts, as well as the useful or practical arts and crafts themselves. According to Google (2014),¹¹¹ use of the word 'technology' in books rose sharply during the second half of twentieth century, levelled off around 1998 and then went into slight decline. The reason for its rise may have been the enormous output of applied science during and after the Second World War. However, the reason for its later decline may be that its most common association is now with the word 'information', which is usually abbreviated as 'IT' and would not be picked up by the Google algorithm. The phrase 'high technology' is from 1964 while its short form 'high-tech' (later 'hi-tech') is from 1972. *New technology* arises from the application of different or innovative systems and methods, whether for the same or different ends.

The word 'technology' also incorporates the applied sciences in its meaning, although not all technologies are derived from science. Most generally, it is the "practical application of knowledge" (Merriam-Webster 2014). In fact, many significant technological developments have been contributed by non-scientists, or rather people with practical skills such as James Watt, an instrument maker; Henry Ford, a metal machinist; Samuel Morse, a professional artist; Thomas Edison, a telegrapher; Guglielmo Marconi, an aristocrat inventor-entrepreneur; and Steve Jobs, a geek and college drop-out. Technological innovations depend more on the skills of technicians than on scientific theories (Coen 2014), and, rather than science driving new technology it is more likely that new technologies are "the force that move science forward" (Wise 1985, p. 229), as no doubt Galileo, Pasteur and the Wright brothers would agree. Much of Galileo's science depended on his use of the telescope; Pasteur's of the microscope and the Wright brothers' miracle of powered flight depended most on the technology of internal combustion and the practical observation of kites.

¹¹¹ Google books N-Gram viewer

Technologies have been with us since pre-historic times, whereas science is a newcomer. But most importantly, technology is about system-based method. Technology may incorporate aspects of art and aesthetics (the functional beauty of an Apple computer springs to mind), but neither is intrinsic to technology. What is intrinsic to technology is the systematic use of particular methods.

It is tempting also to associate technology with mass production, as it has continued to be so at least since the early Industrial Revolution and even earlier with the use of pottery moulds in ancient times. This is because the use of systemic method often leads to reproducibility and hence to mass production – that multiplier of investment capital. Certainly the rise of modern technology is connected with capitalism and the Industrial Revolution, and especially through mass production. Early capitalism encouraged the development of new technologies by simply rewarding them. Arkwright's spinning jenny was probably the first use of technology that resulted in mass production (of cloth) and its associated concentration of a workforce alongside factories. However, these early factories at first used water from fast flowing streams to power the looms. Newcomen's invention of the steam engine to pump water from coal mines enabled coal production to feed new furnaces and factories, while later developments (Watt, Trevithick, Stevenson) enabled the railways that began to connect cities and ports, and powered ships that linked ports around the globe. Edison's breakthrough technologies such as grid electricity, the electric light and the phonograph resulted from an intensive and systematic approach to innovation propelled by the motive for profit.

From a philosophical and ultimately encompassing point of view, Clive Hamilton points to Brian Arthur's definition, 'a phenomenon captured and put to use':

...where phenomena are mostly physical effects such as the release of energy when carbon-based molecules are oxidised and heated, the way light is refracted through a lens, the way wind energy turns a propeller that can drive a turbine, and so on. These myriad phenomena—mechanical, electrical, photonic, biological, nuclear, etc. — are waiting to be discovered by humans and then orchestrated to our benefit (Hamilton 2013, p. 30).

Karl Marx in *Capital*, distinguishes between "natural technology" in the evolution of plants and animals and "human technology" in human history:

Darwin has directed attention to the history of natural technology, i.e. the formation of the organs of plants and animals, which serve as the instruments of production for sustaining their life. Does not the history of the productive organs of man in society, of organs that are the material basis of every particular organization of society, deserve equal attention?... Technology reveals the active relation of man to nature, the direct process of the production of his life, and thereby it also lays bare the process of the production of the social relations of his life, and the mental conceptions that flow from those relations (Marx 1952 [1883], p. 181).

Engels described man as the 'tool-making animal'.¹¹² We lack the ability to evolve the specialised organs Marx and Darwin refer to and instead we develop "specially prepared instruments" that are found "in the oldest caves". Human technology is the tools we develop that shape our relationship with nature – and that in turn shape us in both hand and mind

¹¹² Engels does allow for some other animals that use rudimentary tools in some circumstances.

(Engels 1940 [1876], p. 281). This is an important observation. The creature at the computer screen thinks and acts differently from a tiller of the soil, and so whole societies are shaped.

However, the concept of technology can be confusing. According to other definitions man is not alone in technological behaviour. Other creatures construct technological artefacts such as nests, webs, traps, complex termite mounds and beaver dams. The artefacts that characterise humans are rather machines (Polanyi 1968, p. 1308), complex manufactures with more than one part (such as the bow and arrow)¹¹³ that give us added power over nature. Machine-making was both enabled by and enabled specialisation, exchange value and the creation of ever more complex technologies. It has meant that now, in the contemporary West, we are entirely surrounded by machines, networks and the product of specialised technologies that few understand enough to recreate, but which are in universal use (Aunger 2010).

Slavery and capitalism

The relationship between slavery, capitalism and technology is intriguing. The economic historian, C. Knick Harley, says it is commonly asserted that the West Indies slave trade financed the Industrial Revolution in England (Harley 2013, p. 5), based on Eric Williams' seminal work *Capitalism and Slavery* (1944). Certainly the timing is consistent: slavery and the slave trade was at its profitable height immediately before the Industrial Revolution, yet the slave trade was abolished in 1807 and slavery itself eventually abolished in 1833 within the British Empire (Harley 2013, p. 8). But while the transatlantic slave trade and its profits were based on sugar during the eighteenth century, it was the technological and resultant organisational changes in the cotton industry "that were central to the emergence of a modern economy based on mechanised factory production" (Harley 2010, p. 2). Further,

there is general agreement that technological change lies behind historical economic growth and that the creation of knowledge and technology must be seen as a part of the economy, i.e. endogenous (Harley 2013, p. 21).

Yet while the British cotton industry still depended on slavery for its raw material at the beginning of the Industrial Revolution, by the mid-nineteenth century it was less dependent on slavery due to sourcing from India and the Levant, and also the industry was much less significant. At that time, it was the export of manufactured goods to the Empire and North America that was the source of new profits. The Industrial Revolution in Britain arose from a process of industrial research and development that resulted from the relatively high wages and cheap energy at the time. This provided incentives to find manufacturing techniques that substituted fuel and capital for labour, and this in turn created new knowledge that further enhanced the process of technological change (Harley 2013, pp. 21-23). Thus, plausibly, slavery (in the sugar industry) was one source of capital for the Industrial Revolution. Slavery also was associated with the production of an important raw material (cotton) that was exploited by new technology.

It was the divergent costs of labour and energy that pressed the technological innovations that defined the era. That there was no Industrial Revolution in ancient times indicates that slavery is a negative factor in technological advance. The ancients devised many technological innovations, including steam engines, pumps and watermills, a form of railway across the Corinthian neck, as well as canals in Egypt, Greece and in China.¹¹⁴ However, none of these

¹¹³ Which in turn are composed of shaped wooden lengths, stone, bone or metal tips, gut or hemp stringing and fibrous binding.

¹¹⁴ The Grand Canal dates back to the fifth or sixth century BC

innovations spread far. One reason was the presence of slaves in all ancient societies, which obviated the need for labour saving devices (Cowell 1964, p. 368). Thus, conceivably, the slavery that helped produce the technological advances of the Industrial Revolution did so because it was at a distance from it. The slavery that prevented an ancient Industrial Revolution did so because it was part of the societies that would have been affected. In the ancient world, there was already an army of intelligent robots and thus no need for the evolving labour saving technologies of the Victorian era.

However, capitalism is not essential to technological development. During much of the last century, for example, the command economy of the Soviet Union at least mimicked much of the technological development of the West and in significant ways exceeded it. The indisputably revolutionary *Sputnik* of 1957 is the most obvious example of this. Others include the *Voskhod* space capsule that could land on the hard earth, rather than at sea as the US capsules had to; the world's most popular assault rifle, the Kalashnikov AK-47; superior aircraft such as the MiG 15 fighter during the early 1950s, the MiG 25 Foxbat of the 1970s that could fly at over Mach 3, and the giant Antonov transport plane that is still in use in many parts of the world. Perhaps, as C.P. Snow asserts, it was partly because the Soviet education system managed to blend the arts and the sciences:

An engineer in a Soviet novel is as acceptable, so it seems, as a psychiatrist in an American one. They are as ready to cope in art with the processes of production as Balzac was with the processes of craft manufacture (Snow, 1959, p. 19).

And whilst technological innovation was certainly less frequent before the Industrial Revolution and capitalism, several pre-modern economic epochs are discernable from around 7000 BC that are based on it. The innovations that drove economic (and population) growth include the invention of agriculture itself (c.7000-4000BC), bronze metallurgy (c.4000-1900BC), the iron plough (c.300-930AD) and the spectacle lens (c.1340-1600AD) (Šmihula 2011, p. 66).

In fact, modern economic growth is more dependent on technological innovation than it is on capitalism. Simon Kuznets' Nobel speech on modern economic growth illustrates this in his discussion of economic epochs:

we may proceed on the working assumption that modern economic growth represents such a distinct epoch - growth dating back to the late eighteenth century and limited (except in significant *partial* effects) to economically developed countries. These countries, so classified because they have managed to take adequate advantage of the potential of modern technology, include most of Europe, the overseas offshoots of Western Europe, and Japan (Kuznets, 1971).

Interestingly, the rest of this lecture – presumably an example of the best thinking of the time – has but one dismissive reference to the sustainability of economic growth: “even if we disregard the threatening exhaustion of natural resources, a problem that so concerned Classical (and implicitly even Marxian) economics...” (Ibid), but goes no further on the subject, suggesting that the question of resource depletion was then thought no longer an issue.

Kenneth Boulding, too, was in agreement with the link between economic growth and technology, insofar as technology is applied knowledge. His 1966 paper *The Coming Spaceship Earth* is explicitly about limits. But as far as economic development is concerned:

The cumulation of knowledge, that is, the excess of its production over its consumption, is the key to human development of all kinds, especially to economic development (Boulding 1966, p. 5).

Kondratieff waves

Long-term 50 to 60 year economic cycles, known as Kondratieff¹¹⁵ waves, have been associated with technological innovation since the early twentieth century. The Soviet economist Nikolai Kondratieff identified these phenomena in his book *The Major Economic Cycles* (1925), although some of his observations had been anticipated by Dutch economists, Jacob van Gelderen and Samuel de Wolff, in 1913 (Narkus 2012, p. 12). Kondratieff believed that the crises that punctuate periods between cycles in capitalism were indicative of a clearing away of debris to allow for new technological and economic growth, rather than leading to the inherent doom predicted by Marx. These views were in obvious conflict with Stalinist orthodoxy, and after working in agricultural reform for a time, he was sent to a Gulag labour camp and subsequently executed in 1938. In 1939, the economist Joseph Schumpeter, whose views on ‘creative destruction’ in capitalism and new growth based on “the swarming of technological innovations” (Phillimore 2001, p. 28) benefited from this work, suggested calling the cycles ‘Kondratieff waves’ in his honour.

Several other possible factors that contribute to long economic waves have also been identified, including demographic “baby booms” and debt deflation as part of the credit cycle. However, according to the more mainstream technological innovation theory as championed by Schumpeter, these waves arise from the clustering of innovations that launch technological revolutions, which in turn create leading industrial or commercial sectors.

We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run
– Roy Amara, Institute for the Future

A modification of Kondratieff’s theory was recently developed by the Slovak, Daniel Šmihula, who identified six long-waves within modern capitalist economies. Each of these was initiated by a specific technological revolution and each successive wave is shorter than the one before (Šmihula 2011, p. 51): The financial-agricultural wave occurred between 1600 and 1780, especially in the leading sectors of finance, agriculture and trade. The Industrial Revolution wave occurred between 1780 and 1880, especially involved textiles, iron, coal, railways and canals.¹¹⁶ The technical wave occurred between 1880 and 1940, especially involving the chemical,¹¹⁷ electro-technical and machinery industries. The scientific-technical wave was between 1940 and 1985 and involved the aviation,¹¹⁸ nuclear, space,¹¹⁹ synthetic materials, oil and cybernetic industries. The wave of the information and telecommunications revolution is from 1985 until 2015, and involves telecommunications, cybernetics, “informatics” and the Internet. The sixth wave is a prediction of a ‘post-informational technological revolution’ between 2015 and 2035, involving biomedicine, nanotechnology and alternative fuel systems such as hydrogen.

Unlike Kondratieff and Schumpeter, Šmihula believes that each new cycle is shorter than its predecessor, but does not advance any particular reason as to why this may be so. It is odd

¹¹⁵ Also written as ‘Kondratiev’.

¹¹⁶ Šmihula’s paper says ‘channels’ rather than ‘canals’ here. However, I assume that the former is correct and the latter is a problem of translation, shades of Galileo’s *canali* of Mars.

¹¹⁷ Here Šmihula uses the word ‘chemistry’, which I have changed.

¹¹⁸ Written as ‘air-industry’.

¹¹⁹ Written as ‘astronautics’.

that he refrains from voicing an opinion on this as it his central conjecture. If the observation is valid, then it seems evident that the combined effect of the increasing number and mass of all preceding innovations logically would result in compression of the cycles that spring from later innovations. Earlier technologies facilitate newer technologies, as the printing press spread ideas on heat and steam engines, as smelting produced steel, as railways linked industries that enabled complex manufactures. The accumulation of technical knowledge is geometric and technological progress accelerates. Richardson (2013, p. 161) tends to support this view in his paper on holarchies and technological evolution, in which he says that the idea of a “continual acceleration of change” is credible. The concept of ‘holarchies’, or nested layers of systems, he says, is common in many disciplines, including physics¹²⁰ and biology,¹²¹ but also applies especially to technology. Imagine what could happen if the technological systems of our world were “integrated into an organic whole” supporting both “humanity and nature in an elegant and sustainable way”, he writes (Ibid, p. 167).

Šmihula (2011, p. 53) stresses technological progress and new technologies as decisive factors of any long-time economic development. Each of these waves has an innovation phase, which is described as a technological revolution, and an application phase in which the number of revolutionary innovations falls and the focus is on exploiting existing innovations. Each wave of technological innovations is characterised by the sector in which the most revolutionary changes took place. Every wave of innovations lasts until the profits from the new innovation or sector fall to the level of other, older, more traditional sectors. Šmihula goes on to identify the important difference between technological invention and innovation:

The invention is a making-up of something new which did not exist before. But as such, it may finish at the bottom of a drawer. Only an invention which is applied in practical life can be a real innovation. The source of such innovations may be not only inventions but also imitations taken, for example, from some other society. The economic and social consequences of innovations – regardless of their origin - are the same. From the seventeenth century, European society was the most developed world society and therefore all new inventions arose in Europe. In the more distant past this had not been true and many European innovations were in reality imitations of Arabic and Chinese inventions (Ibid, p. 61).

Carbon

While economic development may occur in technological waves, as many commentators have observed (Commoner, Boulding, Gilding), the technological icons of modernity are all based on the combustion of carbon – coal, oil and gas – that is in effect the stored sunlight from plant life that was laid down during the Carboniferous period of the late Paleozoic era. Those icons – grid electricity, cars and aeroplanes, as well as more lately the computer - enable us to be shielded from the environment and isolated from perceiving the harm that has been mounting especially since the Industrial Revolution. With electricity we have light when the world is dark, warmth when it is cold and we can be cool when it is hot. We are transported in comfort in extremes of weather. We can communicate instantly and we have more information – and trivia – stored than we will ever need. The everyday carbon technology of the West provides more comfort than concern in our daily lives, yet this luxury is fragile because it is based on a limited resource that in its use is ultimately detrimental. In fact, “all of

¹²⁰ Atoms > molecules > cells > organelles > organs > individual > species > planet > solar system > galaxy > universe.

¹²¹ Fibonacci sequences that signify such systems appear in branching trees, the fruitlets of a pineapple, the flowering of artichoke, an uncurling fern, and the scales of a pine cone.

our current environmental problems are unanticipated harmful consequences of our existing technology” (Diamond 2003, p. 44).

However, the significance of a link between capitalism or communism, technological innovation and economic growth may be overdrawn. Some, such as George Monbiot (2014a), deny the force of ideology as “mere subplots” when compared with the real ‘meta-trend’. Rather than any ideology, he says, it was simply the exploitation of carbon reserves that enabled the modern world:

it was neither capitalism nor communism that made possible the progress and the pathologies (total war, the unprecedented concentration of global wealth, planetary destruction) of the modern age. It was coal, followed by oil and gas. The meta-trend, the mother narrative, is carbon-fuelled expansion. Our ideologies are mere subplots. Now, as the most accessible reserves have been exhausted, we must ransack the hidden corners of the planet to sustain our impossible proposition (Ibid).

Monbiot also says that the failure of our society is inescapable because it is built on compound growth and the destruction of the Earth’s living systems. He is not alone in this (Meadows et al 1972, Huesemann & Huesemann 2011, Higgs 2015 for example).

One key aspect of the carbon meta-trend is its relationship to that gift of Prometheus, fire. The idea of the Anthropocene prompts us to see humanity as a geological agent, that our agency involves the use of pyrotechnology to transform materials and thus “shape our social and physical worlds” (Clark 2014). Pre-humans, the hominids of East Africa, may have mastered the use of fire for cooking and for tool-making more than 500,000 years ago. But it was only around 10,000 years ago that the technology of the containment of fire led to the transformation of materials such as metals from ore, bricks and pottery from clay and glass and ceramics from silica, as well as the baking of bread from grain. This containment – ovens, hearths, furnaces, boilers – made possible much higher temperatures than available before and led to the very fabric of ancient civilisations (stone cutting tools, metal spears and armour, bricks and concrete) and ultimately thence to the Industrial Revolution.

This is supported by the insight that two of the three key factors in the domination of the West identified by Jared Diamond (1999) are made possible by the furnace – guns and steel. Germs already existed and were transported to the new worlds largely by accident. In this sense, the European settlement of Australia can be viewed as a clash between the indigenous land-altering technology of open fire and the European metals technology based on contained fire (Clark 2014).

But as Stephen Pyne observes it is industrial combustion that is changing the nature of diversity:

The new energy is rewiring the ecological circuitry of the Earth. It has scrambled ecosystems and is replacing biodiversity with a pyrodiversity – a bestiary of machines run directly or indirectly from industrial combustion (Pyne 2015).

Alternatives

A feminist counter-view may be to put the technology of weaving ahead of that of fire in terms of importance, which is certainly arguable as it is supported by the etymology of the word itself.¹²² Such a view is also consistent with the fact that little of this ancient technology remains – fabric is

¹²² The Greek word root of ‘technology’ is from ‘teks’ – ‘to weave’ or ‘fabricate’.

soft and decays, metal is hard and durable. Nevertheless, Penelope's weavings and re-weavings in Homer's *Odyssey* establish it in ancient times as do sophisticated Egyptian relics from much earlier periods. Various forms are observable in many indigenous societies today, depending on the plant fibre available. Weaving enables not only the production of clothing from plant or animal fibre, but also enables lightweight containers (baskets) for the transport and security of food, the making of shelters and the production of portable fencing for herding as was practised in Neolithic times. It is a technology that is not fuelled by carbon and, ironically, runs counter to the 'mother narrative'.

A broader alternative to the mother-narrative is a recent article by Michael Le Page, which imagines a modern world in which fossil fuels do not exist (Le Page 2014, pp. 34-39). He suggests that such a world would be dependent on hydroelectricity, with that technology possibly originating in Norway and Switzerland rather than in England. Such a world may have more highly developed electrical motors and batteries, cleaner air, and more electric powered public transport. Long-distance travel would be by sailing ship, electric railway and possibly by hydrogen-filled airship. However, he points to an apparent consensus that at best, there would be much slower growth and such a civilisation could not support a similar population to the present, even if industrialisation did proceed in this manner. This would be due to limiting factors such as an impossible number of dams required, as well as lack of materials required for construction. The intensity of fossil energy sources is very hard to replace (Le Page 2014, p. 39).

Silicon

Kenneth Boulding (1966) would have agreed about the carbon meta-trend. However, he was optimistic about the possibility of technology to provide answers to the exhaustion of carbon reserves:

Failing this [development of atomic fusion], however, the time is not very far distant, historically speaking, when man will once more have to retreat to his current energy input from the sun, even though this could be used much more effectively than in the past with increased knowledge. Up to now, certainly, we have not got very far with the technology of using current solar energy, but the possibility of substantial improvements in the future is certainly high.

In line with Boulding's prophetic observation, the most recent 'meta-trend' or 'mother narrative' arises less from the exploitation of carbon and more from its fraternal element, silicon: that is the knowledge explosion resulting from interlinked computers.

The history of computer development really starts in Bletchley Park in England during the Second World War, when Tommy Flowers and Alan Turing led teams that were trying to break German military codes and applied computing theory to the problem. In so doing they constructed ten electronic programmable computers, each, appropriately, called 'Colossus'. Turing himself pointed out two key advantages of electronic computer technology when he delivered a lecture to the London Mathematical Society in 1947 on the automatic computing engine (ACE). Digital computers were unrestricted in both their accuracy and their applications:

From the point of view of the mathematician the property of being digital should be of greater interest than that of being electronic...That the machine is digital however has more subtle significance. It means firstly that numbers are represented by sequences of digits which can be as long as one wishes. One can therefore work to any desired degree of accuracy. This accuracy is not obtained by more careful machining of parts,

control of temperature variations, and such means, but by a slight increase in the amount of equipment in the machine... This is in sharp contrast with analogue machines...where each additional decimal digit required necessitates a complete redesign of the machine, and an increase in the cost by perhaps as much as a factor of 10. A second advantage of digital computing machines is that they are not restricted in their applications to any particular type of problem. The differential analyser is by far the most general type of analogue machine yet produced, but even it is comparatively limited in its scope. It can be made to deal with almost any kind of ordinary differential equation, but it is hardly able to deal with partial differential equations at all, and certainly cannot manage large numbers of linear simultaneous equations, or the zeroes of polynomials. With digital machines however it is almost literally true that they are able to tackle any computing problem. A good working rule is that the ACE can be made to do any job that could be done by a human computer, and will do it in one ten-thousandth of the time. This time estimate is fairly reliable, except in cases where the job is too trivial to be worth while giving to the ACE (Turing 1947, p. 509).

Just as the exploitation of carbon had an enormous impact across a vast range of industries, so has the exploitation of silicon shortly after the Bletchley Park era. This was when vacuum-tube valves were replaced with transistors¹²³ and then microchips in much smaller computers through exploiting the semi-conducting properties of silicon. It was also when photovoltaic cells began to be developed that exploited the capacity of silicon to translate photonic energy into electronic energy¹²⁴. But while carbon is exploited directly in vast quantities for both energy and materials, silicon is exploited indirectly and in much lesser quantities for the manipulation of vast amounts of data, as well as for harnessing energy from the sun. Compared with carbon, our relationship to silicon is not, and need not be, voracious.

The silicon-based development of linked computers has since enabled data gathering and manipulation across all fields and industries as well as creating new endeavours such as those based on chaos theory and the information sciences. The origin of the DIKW (data-information-knowledge-wisdom) hierarchy¹²⁵ concept is uncertain (Boulding 1955?), but linked computing has enabled a new universe of possibilities within the first three categories. The fourth category, wisdom, may be enhanced by the availability of better information and knowledge on which to base good judgement.

Again, exponential growth is apparent, but unlike carbon technologies, silicon-based information technology uses a virtually limitless resource – data – that is created and processed at increasing rates. Moore's Law, that computing power doubles approximately every 18 months, is looking a little ragged now that processing chips are at near sub-atomic levels. Yet the law has held for the past several decades. And in any case, the growth of the amount of information available is independent of growth in computing power; it relates more closely to storage and retrieval capacity. This most recent technological trend forms a kind of symmetry with the major technological revolution of the mid-millennium: printing, which produced a radical increase in the sharing of knowledge and ideas, and which therefore made the Industrial Revolution possible.

¹²³ Initially germanium rather than silicon was used for transistors

¹²⁴ Although Alexandre Becquerel noticed the conversion of light into electricity in 1839, practical photo-voltaics were first developed at the Bell laboratories in 1954.

¹²⁵ Often expressed as 'data is not information, information is not knowledge, knowledge is not wisdom'.

Other technologies

Brundtland (1987) first mentions (new) technology at page 13 as a “mainspring of economic growth” which has the potential to reduce “the dangerously rapid consumption of finite resources”, but which risks new forms of pollution and new life forms that could change the direction of evolution. Later the Brundtland report also asserts that technology will continue “to change the social, cultural, and economic fabric of nations and the world community” but that new technology encompasses both promises and risks. The promises outlined in the report include information and communication technologies that can benefit productivity as well as energy and resource efficiency.

The Brundtland report also highlights the advantages of new materials including composites that require less energy and less matter to manufacture. She mentions how biotechnology could dramatically improve human and animal health and how renewable plant-sourced energy may substitute for non-renewable fossil fuels, as well as how engineered crop varieties “could revolutionise agriculture”. Biotechnology could be an answer to polluting products as well as to the issue of hazardous waste disposal. New satellite remote sensing technology could ensure better short-term agricultural forecasting and longer-term “optimal use of the Earth's resources” by monitoring climate change, marine pollution, soil erosion and plant cover (Brundtland 1987, pp. 150-151).

Some of these examples did not quite work out as forecast, however. Brundtland also mentions “new plant strains that can fix atmospheric nitrogen” and so reduce pollution from chemical fertilisers. The use of nitrogen-based fertiliser started to peak in 1988, around the same time as the Brundtland report was issued, after its invention early in the twentieth century had “incited fears of a runaway technology causing a rain of N” (Frink et al 1999, p. 1179). While the Food and Agriculture Organisation (FAO) cautions that the method is not effective in all plants, a 1995 technical report on the concept of biological nitrogen fixation using bacteria that naturally occur in the roots of some plants, summarises such a development as suitable for farming of tropical legumes:

Since nitrogen is commonly the most limiting plant nutrient in arable farming in the tropics and also the most expensive element as a mineral fertilizer, biological nitrogen fixation (BNF) holds great promise for smallholder farmers in sub-Saharan Africa. Alley farming systems which use leguminous woody species in the hedgerows can reduce or eliminate farmers' needs for commercial N fertilizer (Mulongoy 1995).

However, in 2013, twenty-six years after the forecast in the Brundtland report, a different method for fixing atmospheric nitrogen was announced by researchers at the University of Nottingham after a decade of research. Rather than using new plant strains, the method uses bacteria that naturally occur in sugar cane that are harvested to provide a sustainable biological coating for any plant to enable it to fix nitrogen (KurzweilAI 2013).

While this alternative nitrogen-fixing technology appears to be beneficial, the Brundtland report warns that other technologies may have negative consequences. The report says developments in seed technology could lead to greater dependence on fewer crop varieties owned by even fewer transnational companies. Also, new materials may create previously unknown hazards to health. Further, the report anticipates the genetically modified (GM) food debate by pointing out that genetically engineered organisms may have unforeseen effects on the environment.

Pessimism

One recent text stands out as a denial of the possibility that technology can be an answer to unsustainability. With *Technofix*, Canadians Huesemann & Huesemann (2011), who aptly live on a small island in British Colombia, have drawn praise from some ecologists for their “mythbusting”¹²⁶ explanation of “why technology won’t save us or the planet”. After showing that all new technologies cause significant unanticipated problems, the Huesemanns suggest that there are basically three types of technological remedy: (1) counter technologies that neutralise the negative effects of other technologies, such as environmental remediation (2) social fixes, which use technology to solve social, economic, political, or cultural problems, such as industrialised agriculture to solve world hunger and (3) efficiency improvements to technological processes, such as better fuel efficiency of cars (Huesemann & Huesemann 2011, p. 73).

Although lacking clarity about which category of remedy it falls, the Huesemanns are pessimistic that even renewable energy technologies contribute to sustainability, contrary to the opinions of many ecologists, as “all renewable energy technologies are expected to have significant environmental impacts” when deployed on a sufficiently large scale. They base this view on “land limitations, severe environmental impacts and public opposition” as well as the greater expense of particularly solar technology compared with coal (Ibid, p. 132). This view is questionable. Certainly there has been public opposition to renewable wind farming on both land and sea, where there has been visual, auditory and birdlife impacts. But this has been observably less than the sort of opposition engendered by coal and nuclear power plants. As far as solar energy is concerned, there has been opposition to large-scale solar farms in the UK for example, where they may have been sited “insensitively” (Gosden 2014), but this could not be said to be a wave of discontent that has prevented such harvesting. Moreover, the future of solar energy is as much about decentralised domestic and local production as it is about large scale grid-based energy delivery, and the cost of renewables at the point of delivery is already lower than coal (Parkinson & Gilding 2014), only three years after the Huesemanns’ assertion to the contrary.

Nonetheless, more ominously Huesemann & Huesemann outline three general preconditions for environmental and societal collapse “(i) rapid growth in resource use and pollution, (ii) limited resource availability and waste absorption capacity, and (iii) delayed responses by decision-makers when limits have already been exceeded or soon will be” (Huesemann & Huesemann 2011, p. 139). While this text has weaknesses, such as its tendency to accept that unanticipated problems are inevitably of a great magnitude compared with the benefits of a technology, these three preconditions are cause for concern. The first two are largely met - partly due to the vastly increased growth and consumption in both China and India in the past few decades, combined with the foreseeable exhaustion of global oil supplies and the obvious incapacity of the atmosphere to absorb more carbon dioxide without dramatically affecting climate. With respect to the third precondition (delayed response by decision-makers), the planetary scale of the problem suggests that any delay may render any action too late.

To illustrate this issue of scale, it has been observed that in the time leading up to Australia’s 1964 ‘Voyager’ naval disaster, which involved the collision between a destroyer and an aircraft carrier, there was an interval of 45 seconds during which no avoidance manoeuvre whatever could have averted the tragedy because the speed and course of the ships could not be varied enough in that time (Hickling 1965, p. 141). The momentum of ships is large. Yet it is infinitesimal when compared with the momentum of the planet’s biosphere and the destructive course it is following. Over how many times longer than 45 seconds will it matter not at all whatever corrective action is taken? Unless of course, that point in time has already passed.

¹²⁶ Rees, W, University of British Colombia, quoted in the book frontispiece.

Optimism

Whether or not it is indeed too late, technology is involved in yet another paradox, but with potentially positive consequences. Edward Wilson, the Harvard biologist mentioned in chapter 3, draws attention to the “inconvenient truth” that no ecosystem under human pressure can be made sustainable without humanity knowing all the species that compose it. The paradox is that the more species that we extinguish, the more we discover. We currently identify less than two million, whereas there may be at least five million or even possibly 100 million species on Earth (Wilson 2013). At microbial level, 99 per cent of such organisms remain unknown to us: the soil remains a “*terra incognita*” to our species (van der Hout 2014, p. 435). Nevertheless, the technology that is now helping to identify and preserve species, which involves a kind of barcoding of DNA sequences, is some distance from Heidegger’s lament.

Technology optimists include the US industrial ecologist Jesse Ausubel, whose article *Can Technology Spare the Earth?* (1996) outlines how improving efficiencies in resource use through especially silicon-based technology can restore the environment even as the population grows:

Families named Smith, Cooper, and Miller people our nation because until not long ago most of us beat metal, bent casks, and ground grain. Now few workers hold such jobs. So far, except in video, we are not named Programmer, Sub-Micron, and Genesplicer. We easily forget how much the modern world has changed and yet how early our day is. We forget the power of compounding our technical progress, even at one or two percent per year. Knowledge can grow faster than population and provide abundant green goods and services. The message from history is that technology, wisely used, can spare the Earth. You can click on it.

This message echoes that of Marx and Engels more than a century and a half ago. While Marx attacked Malthus’ views of the limits to growth and the inevitable impoverishment of the working class (cited in Dresner 2008, pp. 13-14), Engels asserted that any geometric increase in population would be matched by a geometric increase science and its application:

Yet, so as to deprive the universal fear of overpopulation of any possible basis, let us once more return to the relationship of productive power to population. Malthus establishes a formula on which he bases his entire system: population is said to increase in a geometrical progression – 1+2+4+8+16+32, etc.; the productive power of the land in an arithmetical progression – 1+2+3+4+5+6. The difference is obvious, is terrifying; but is it correct? Where has it been proved that the productivity of the land increases in an arithmetical progression? The extent of land is limited. All right! The labour-power to be employed on this land-surface increases with population. Even if we assume that the increase in yield due to increase in labour does not always rise in proportion to the labour, there still remains a third element which, admittedly, never means anything to the economist – science – whose progress is as unlimited and at least as rapid as that of population. What progress does the agriculture of this century owe to chemistry alone – indeed, to two men alone, Sir Humphry Davy and Justus Liebig¹²⁷! But science increases at least as much as population. The latter increases in proportion to the size of the previous generation, science advances in proportion to the knowledge bequeathed to it by the previous generation, and thus under the most

¹²⁷ Both eminent chemists

ordinary conditions also in a geometrical progression. And what is impossible to science? (Engels 1844).

Incongruously, it is a similar sort of argument that now attaches to its opposite ideology of neoliberal economics (there will be no resource crisis because applied science and technology will be “incentivised” to find and develop substitutes as resources become harder to extract and their price rises). However, the argument is also consistent with the key advantage of a silicon-based technology – that it uses vastly less material resource and more an inexhaustible virtual resource: it grows geometrically, building upon the ‘knowledge bequeathed to it by the previous generation’ as Engels suggested in a different era.

Jevons paradox

Much technological development has been driven by the quest for efficiency, highlighted by Watt’s improvements to Newcomen’s steam engine and the continuing pursuit of more efficient internal combustion. The IPCC endorses efficiencies through improved technologies as a way of mitigating climate change and promoting sustainable development (IPCC 2014a, s.4.3.6). But all is not as it seems; efficiency can be a mirage that recedes as it is neared. The Jevons paradox (or ‘rebound effect’) is an observation made about coal consumption in the nineteenth century and has much wider application for all forms of technological efficiency. Jevons (1865) projected that the consumption of coal in Britain would follow an exponential curve so that it would be almost infinite by 1950, the middle of the following century, if its then rate of increase were maintained. At that time many in the UK worried that coal reserves were rapidly dwindling, but some believed that improving technology would reduce coal consumption. Jevons argued that this view was incorrect, as further increases in efficiency would tend to increase the use of coal, as Watt’s improved steam engine had generated more demand for the resource. More generally, the proposition is that as technology progresses, the increase in efficiency with which a resource is used tends to increase the rate of consumption of that resource.¹²⁸

This tendency is apparent because greater efficiency makes the resource effectively cheaper and hence will tend to be used and depleted faster. However, the degree of this tendency does depend on the elasticity of demand for the resource, so there is not a rigid link between efficiency and resource use. Demand elasticity is partly a function of the availability of substitutes, and this also must be taken into account. According to energy economist Harry Saunders (1992, p. 131), there is a further factor linking efficiency with increased energy consumption: at the macroeconomic level, more efficient technology also leads to faster economic growth, which in turn increases energy use throughout the economy. Thus technological progress that improves energy efficiency will tend to increase overall energy use.

Nevertheless, the Jevons paradox assumes an unregulated market, whereas in reality it is possible to tax undesirable consumption. As Joe Stiglitz (2014) said recently in respect of deficit reduction and the carbon tax, “it’s absolutely clear that it’s better to tax bad things than good things; that way you get a double dividend”. Finally, on this efficiency issue, the Jevons paradox obviously does not result in the same concern when the energy source is renewable: as photovoltaics, for example, are becoming more efficient, they are able to generate more electricity per unit. But there is no concern about depletion of the energy resource. That concern only applies where the energy source is not renewable. Technology

¹²⁸ The Jevons paradox is in principle similar to the Downs–Thomson paradox, that increasing road capacity can make traffic congestion worse.

and sustainability is less about fuel efficiency and more about the nature of the technology and the form of energy it uses.

Automation, artificial intelligence and development

For both the developed and developing worlds, an important technological issue is associated with automation and artificial intelligence (AI). Al Gore, for example, believes that:

The technological extension of the ability to think is therefore different in a fundamental way from any other technological extension of human capacity... [thus the impact of AI] will be far greater than that of any other technological revolution (Gore 2013, p. 40).

David Roden (2015, pp. 16-17), in discussing the concept of ‘posthumanism’, speculates on the implications of a robot or computer system with better than human reasoning ability. Such a possible super-intelligence may be ambivalently good or evil. He cites the cryptographer Irving Good as saying that since the design of machines is an intellectual activity, then an intelligent machine could design even better machines, resulting in an “intelligence explosion”, leaving human intelligence far behind. “Thus the first ultra-intelligent machine is the last invention that man need ever make” – as long as it can be kept under control (Good 1966, pp. 33-4). The cosmologist Stephen Hawking agrees. In a widely reported BBC interview of 2 December 2014 discussing new anticipatory software that enables him to communicate more easily, he said he was worried about the idea of creating machines that think because an artificial intelligence would be able to independently re-design itself at an ever-increasing rate, so that humans would be “superseded”. While Isaac Asimov anticipated and attempted resolution of such an issue sixty years ago with his three laws of robotics,¹²⁹ it is conceivable that a sophisticated AI could re-program itself or its progeny beyond such constraints, or become dangerously dysfunctional as did HAL in Clarke’s *2001: A Space Odyssey*.

Asimov’s laws are an example of highly distilled AI regulation. According to *The Economist* (9 May 2015), coping with AI will be relatively easy because we are used to controlling autonomous bureaucracies, markets and armies, all of which can do great harm without appropriate regulation, oversight and means of accountability. It points out, though, that the most important safeguard for controlling a future AI will be an *off* switch.

The current approach to AI though is to ignore the goal of human-like intelligence or understanding and rather teach machines through vast numbers of example, rather than by adopting certain principles. Known as ‘machine learning’, this is how the first successful machine translation system, *Candide*, worked¹³⁰. Google Translate, with its vast database uses the same approach. According to one of its software engineers:

you can take one of those simple machine-learning algorithms that you learned about in the first few weeks of an AI class, an algorithm that academia has given up on, that’s not seen as useful—but when you go from 10,000 training examples to 10 billion training examples, it all starts to work. Data trumps everything (Estelle quoted in Somers 2013, para. 60).

¹²⁹ The first law is that a robot must protect its human master from harm. The second law is that a robot must obey the commands of its human master, unless it conflicts with the first law. The third law is that it must protect itself unless it conflicts with the first or second laws. In later stories there is also a ‘zeroth law’, that a robot must primarily protect humanity.

¹³⁰ *Candide* used 2.2 million pairs of sentences, mostly from the bilingual proceedings of Canadian parliamentary debates for its English-French translations (Somers 2013, para. 56).

The technique is so effective that Google Translate people do not speak most of the languages that the application translates. Engineers are much more important to the system than linguists. Translation through machine learning is “data-mining at a massive scale” (Ibid, para. 61). It is not understanding, nor is it anything like self-awareness.

But while AI is yet to achieve “singularity” – the point at which machine (general) intelligence exceeds that of humans – nevertheless automation, or the replacement of human labour by embodied capital, appears to be progressing at pace, exemplified by the explosion of computerisation and robot factories of recent decades. It is not just manufacturing employment that is at risk in both rich and poor countries; more skilled jobs are susceptible to replacement by machine intelligence, including routine legal work. Already journalism is often the product of software rather than human effort, as are translations due to *Google translate*.

Some are skeptical of the degree of automation possible due to Polanyi’s paradox¹³¹ and the recurring phenomenon of “automation anxiety” since the time of the Luddites (Autor 2014, pp. 2-3). Nevertheless, the futurist Martin Ford’s (2009 p. 237) view is that, as technology accelerates, machine automation may create a ‘downward economic spiral’ as predicted by Marx, due to overproduction coupled with unemployment and hence lack of consumer demand. Automation is already established even in developing economies and there is no possibility of arresting the trend: “the world economy is a closed system”, he says (Ibid, p. 97). However, Ford does not accept Marxist solutions, instead valuing the consumer more than the worker-producer. He proposes that as automation accelerates, people in developing countries should be paid incentives for conserving resources and protecting the environment, thus maintaining consumer demand while at the same time “decoupling economic prosperity from negative ecological impact” (Ibid, p. 198).

More recently, but for different reasons, the Intergovernmental Panel on Climate Change (IPCC) is in line with such thinking. The Panel finds that the basic clean energy and nutritional needs of billions of people remain unmet. Therefore, there is a need to adopt non-conventional incentives “for technology innovation and diffusion processes that respond to social and environmental goals” (IPCC 2014a, Ch. 4, p. 25). The World Bank too, believes that innovation and technology can lead to better development models. Its former Chief Innovation Officer, Chris Vein, says that:

technology evolves and the possibilities of movements like the 'Internet of Everything' come in to focus, new and innovative approaches become the antidote to development in the usual manner (Vein 2013).

This is noticeably different from the sort of approach suggested by earlier sustainable development advocates. Schumacher (1989 [1973], p. 61) of ‘small is beautiful’ fame, advocated “maximum well-being for minimum consumption” and small-scale, local “appropriate” technologies for the developing world. As John Phillimore (2001, pp. 24-25) points out, Schumacher’s ideas, once influential, fell from favour as Schumpeterian big-scale technological innovation ideas showed success in the economic development of East Asia. Although the two economists are usually seen as opposites, they actually have much in

¹³¹ Polanyi’s paradox: our tacit knowledge of how the world works often exceeds our explicit understanding. We understand how to use our body or drive a car, but can do so without any knowledge of physiology or the dynamics of transport objects. It is therefore very difficult to create a robot to emulate human capability (Michael Polanyi 1966).

common, not least that Schumacher was once Schumpeter's pupil — in Bonn in 1929. Both were especially interested in technology and its relationship to economic growth. Both favoured entrepreneurial innovation, although politically the two were rather further apart (Narkuss 2012).

Transitions

I think that four hundred years hence the power question in England may be solved somewhat as follows: The country will be covered with rows of metallic windmills working electric motors which in their turn supply current at a very high voltage to great electric mains. At suitable distances, there will be great power stations where during windy weather the surplus power will be used for the electrolytic decomposition of water into oxygen and hydrogen

— JBS Haldane, Daedalus, Science and the Future, Cambridge, 4 February 1923.

The question as far as technology and development is concerned, is how to encourage more sustainable 'green' (Schumacherian) technological development on a Schumpeterian scale. This essentially depends on energy source (Phillimore 2001, p. 27). Bill McKibben (2008 p. 206), while favouring small-scale, local and appropriate technologies in the Schumacherian tradition, also allows that centralised 'clean-coal' and even nuclear power generation should not be ruled out in the "desperate" fight to slow carbon emissions (Ibid, p. 144). However Phillimore points out that information and communication technology (ICT) is not inherently green because it has aspects that — shades of Jevons — encourage more energy use, such as increased travel, materials and energy consumption based on the production shift to Asia. Ultimately he laments that the ICT paradigm depends on fossil fuels as its main source of energy (ibid). This is still true, but increasingly less so, as silicon replaces carbon in the generation of electricity in both grid and off-grid applications, leading to a transformational 'tipping point' (Parkinson & Gilding 2014; CEA 2016; Forsythe 2017).

There is a widespread view that coal, oil and gas will be with us for many more decades, despite concerns about climate change. This is based on a world view of an energy system defined by large, long-life assets like power stations and coal mines, whereas there is an emerging distributed system that more closely resembles the growth of mobile phones — a consumer driven, rapidly shifting market with diverse players. It has been argued that, driven by dramatic price falls in solar, the energy system may be on the verge of a revolutionary transformation. This would involve a shift from fossil fuels to renewables; a transition from centralised utilities to distributed house scale generation; a car industry that might enable storage of renewable energy; and perhaps global energy price deflation in stark contrast to forecasts of peak oil and spiralling prices (Parkinson & Gilding 2014).

Even though this transition has just begun, the challenge to regulatory frameworks and institutional arrangements are already felt. In many countries policy makers are caught between the demands of consumers testing the current boundaries of institutional structures and utilities that want to defend their business models from what is a serious challenge.

In Africa, renewable energy has already made inroads at the non-grid household level. Kerosene lamps have been described as the "vampires" of developing communities on the continent because although used in almost every home they are expensive, using up to one third of average household income for their fuel. These lamps also provide poor light, emit noxious fumes and cause house fires and child poisonings. As of 2014, it was estimated that 110 million households in Africa did not have electricity. But recently, new solar powered lights manufactured in China have begun to replace kerosene lighting. These lights cost eight dollars each, cost nothing to run and have none of the other disadvantages of kerosene lamps.

SunnyMoney, a supplier of the lights, which is now the biggest solar lighting company in Africa, has sales of more than one million units per year. Profits are returned to local communities (*Science Show* 2014). Because kerosene is derived from oil and uses still more fuel in its transport, this solar lamp project has the potential to reduce up to three per cent of global oil consumption (Miller et al 2013).

Already, within key economic sectors energy demand is not what might be expected. According to *The Economist* (2014), agriculture is now far more energy-intensive than manufacturing. While this appears counter-intuitive, considerable energy is needed to produce fertilisers, and in many countries much electricity is needed to pump water from deep aquifers and distant rivers, for example. Each dollar of agricultural output needs four or five times as much energy to produce as the same value of manufactured goods. The transition to a future sustainable agriculture to feed ten billion people will demand a lot of energy.

The cloud

The 'Internet of Everything' (IoE), or 'Internet of Things' (IoT) concept mentioned above is based on cloud data storage and the wireless interconnection of myriad computing devices through the Internet. Increasingly it is powered by sunlight directly, as illustrated by Apple's decision to convert all its data centres as well as some of its manufacturing to solar power (Goldenberg 2014b). Of the IoT's many potential applications, two in particular stand out in relation to sustainability. These are its potential for environmental monitoring and remediation, and its potential for energy management. Monitoring of the environment is made vastly more sophisticated through applications of the IoT. There is potentially limitless data available from environmental sensors¹³² already, and when wirelessly connected through the cloud, both real-time and historical information is made available with which to link with social and economic data, and therefore on which to target remediation and mitigation decisions (Sense-T 2014).

With respect to energy management, cloud connectivity makes it possible to individually and remotely manage energy-producing and energy-using devices, thus minimising energy production through matching it more exactly to real-time demand. While this does not yet drive a stake through Jevons' resilient heart, this oblique approach must help reduce energy needs.

Of course the inventor and futurist, Buckminster Fuller, believed this half a century ago:

You may very appropriately want to ask me how we are going to resolve the ever-acceleratingly dangerous impasse of world-opposed politicians and ideological dogmas. I answer, it will be resolved by the computer. Man has ever-increasing confidence in the computer; witness his unconcerned landings as air transport passengers coming in for a landing in the combined invisibility of fog and night. While no politician or political system can ever afford to yield understandably and enthusiastically to their adversaries and opposers, all politicians can and will yield enthusiastically to the computers safe flight-controlling capabilities in bringing all of humanity in for a happy landing (Buckminster Fuller 1969, p. 44).

Thermodynamics

The relevance of thermodynamics to the issue of the sustainability of the anthropocene Earth is that the planet is, in effect, a 'closed' thermodynamic system. However, in the language of

¹³² According to the World Economic Forum there will be one trillion sensors connected to the Internet by 2022 (WEF 2015, p. 16).

applied physics, this is different from a completely *isolated* system: a closed system does exchange energy (in the form of sunlight and other radiation) with its surroundings while an isolated system exchanges neither energy nor mass. An isolated system is a theoretical construct, since within the real universe there must always be the effect of gravitation and exchanges of particulate matter, however small.

The laws of thermodynamics have been described by the Colombia theoretical physicist, David Albert, as “one of the monumental achievements of the physics of the nineteenth century”, a “beautiful and breathtakingly concise summary of the behaviours of macroscopic material systems” (Albert 2015, p. 3).

The Earth does contain the means for the creation of energy, such as reserves of coal, oil and gas. However, those reserves are limited to perhaps a century or two and are due to the sunlight of past eons and the process of photosynthesis. Other apparently internal energy sources such as hydro-electricity, wave and wind power are also the indirect result of sunlight, albeit with unlimited availability. The burning of biomass also appears internally-sourced, whereas it too results from external solar input. Tidal power is largely derived from the orbit of the Earth relative to the moon and the sun, combined with the effects of the Earth’s rotation. It is externally sourced due to gravity. Nonetheless as the tides slow the rotation of the Earth albeit infinitesimally, it does have an ultimate limit due to the law of conservation of energy. Lastly, there are two genuinely internal energy sources – geothermal and radioactivity (from uranium and potentially thorium deposits). While geothermal supplies, including off-grid heat pump extraction, are probably available for the very long-term, supplies of uranium are estimated to last perhaps only 200 years even ‘at current rates of consumption’ (Fetter 2009).

Popular sustainability literature suggests that energy sources can be conceived of as either ‘renewable’ or ‘non-renewable’. However, energy sources also can be seen as either external or internal to the Earth’s thermodynamic system. Most energy sources are based on the input of sunlight, whether over the shorter or longer term. The key point is that sustainable energy must balance the flow from external sources with its use over time - that is, power. Internal sources are a limited stock, whereas we must focus on matching the external flow rather than the internal stock to become sustainable.

That leaves other energy sources that are as yet little more than theory. In particular, this means nuclear fusion, rather than the controlled fission reaction currently used in nuclear power stations. Fusion research, however, although currently funded by an international government consortium centered on France is typically “ten years” from any practical development and is frequently announced as such, as recently by the US military manufacturer, Lockheed Martin (Tollefson 2014).

Still, the US science writer, Dawn Stover, disputes that so-called renewable forms of energy are as renewable as they are thought to be. She says that ‘renewables’ need non-renewable resources to be effective, including the stuff of photovoltaic panels, precious groundwater for solar and geo-thermal, steel and rare Earths¹³³ for wind turbines as well as vast amounts of concrete for hydro-electric dams. In many countries, biomass for heating and cooking results in “severe deforestation and air pollution”. Further, meeting the world’s energy demands from such sources in the foreseeable future is completely impracticable as it would require the construction of an impossible number of solar farms, wind turbines and the like (Stover 2009, p. 1).

¹³³ Rare earths such as neodymium are used in wind turbine generator magnets.

Her critics, however, point to the recyclability of photovoltaics and steel, as well as the fact that the “rare Earths” of generator magnets are not actually so rare, as they are distributed in the Earth’s crust at about the same volume as copper. Richard and Marc Perez of the Atmospheric Science Research Center, on the other hand, point to a comparison between renewable and finite energy reserves measured in terawatt-years (TW-yr).¹³⁴ Of the finite (non-renewable) reserves, coal has estimated total reserves of 900 TW-yr, petroleum 240, natural gas 215 and uranium 90-130. The total world energy use is about 16 TW-yr each year (Perez & Perez 2009). This means that if coal were the only source of energy it would last for only a further 56 years. Likewise, petroleum would last only 15 years, natural gas 13 years and uranium around ten at current usage rates. By contrast, potential hydro and biomass energy could each account for about a quarter of energy needs indefinitely, wind for two or three times current consumption indefinitely, ocean thermal about half, and geothermal about one tenth. However direct solar potentially could provide more than *1400 times* our current world energy consumption – indefinitely.

The US ecological economist, Eric Zencey’s view, is that economics is subsumed by energy deficits and that our current use of energy is but a frantic moment that must inevitably diminish:

Seen through the thermodynamic lens, what has been called the Industrial Revolution is, more properly, the Hydrocarbon Revolution, a once-in-planetary-history drawdown of stored sunlight to do work and make wealth in the present. The petroleum era will most likely depart as suddenly as it came; in the grand sweep of geologic time, our use of petroleum is just an instant, a brief burst of frantic activity that has produced exponential growth in wealth and human population—and in humanity’s impact on planetary ecosystems (Zencey 2013 pp 73-74).

He goes on to sketch the history of ecological economics through Georgescu-Roegen and his pupil Herman Daly, who developed a thermodynamic critique of economics and the non-market “ecosystem services” it takes for granted (Zencey 2013, p. 77).

Entropy

The concept of entropy relates to matter, biology and knowledge as well as to energy. An isolated system is more restrictive than a closed system as it does not interact with its surroundings in any way. Mass and energy remain constant within the system, and no energy or mass transfer takes place across the boundary. As time passes in an isolated system, internal differences tend to even out and pressures and temperatures tend to equalise, as does density. A system in which all equalising processes have gone practically to completion is in a state of thermodynamic equilibrium.

The second law of thermodynamics for isolated systems states that the entropy of an isolated system not in equilibrium tends to increase over time, approaching maximum value at equilibrium. Overall, in an isolated system, the internal energy is constant and the entropy can never decrease. However, a *closed* system’s entropy can decrease, for example when heat is extracted from the system.

According to the mathematician-economist Nicolas Georgescu-Roegen, who was particularly influential in the development of ecological economics, understanding what entropy is relates to the distinction between *available* and *unavailable* energy. “This distinction is anthropomorphic” because energy is available or unavailable according to whether it is suitable for human use.

¹³⁴ One terawatt equals one trillion (or 10^{12}) watts.

Within “an isolated system, the amount of energy remains constant (the first law of thermodynamics), while the available energy continuously and irrevocably degrades into unavailable states (the second law). Therefore, irrespective of technical detail, “entropy is an index of the amount of available energy relative to the absolute temperature of the corresponding isolated system” (Georgescu-Roegen 1986, pp. 3- 4).

Georgescu-Roegen also outlines how matter is similarly affected by entropy and in so doing denies that that continuous recycling, or re-creation of ordered states of matter is feasible:

It is an elementary fact...that matter also exists in two states, available and unavailable...just like energy, it degrades continuously and irrevocably from the former to the latter state. Matter, just like energy, dissipates into dust, as is best illustrated by rust, by wear and tear of motors [or] of automobile tyres (Ibid, p. 7).

More specifically this will lead to scarcity of materials for, as he puts it, “materials vital for the current hot technology will sooner or later become extremely scarce...even scarcer than the available energy from fossil fuels”, which then exposes the “logical weaknesses” of Herman Daly’s (1973) promise of salvation through steady-state economics (Ibid, p. 8).

The Nobel laureate, Erwin Schrödinger, who was invited to live in Ireland by Eamon de Valera after the Anschluß, lectured in Dublin in 1943 about life from a physicist’s perspective. The lectures centred on the notion of entropy and the laws of thermodynamics. Usefully for this dissertation, his lectures define ‘life’ in terms of a kind of ‘entropy border’. Inside the boundary of a living organism is order, or negative entropy.¹³⁵ This order within is achieved at the expense of increasing entropy without, that is in its environment:

entropy, taken with the negative sign, is itself a measure of order. Thus, the device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists continually sucking orderliness from its environment (Schrödinger 1944, p. 26).

James Lovelock picked up this theme when working at the Jet Propulsion Laboratory pondering how to identify life for the first Mars lander during the 1960s. His first step was to look for “entropy reduction” as it must be a characteristic of every life form (Lovelock 2000 [1979], p. 2). He also goes on to describe the key but elusive nature of entropy in the following passage:

...few physical concepts can have caused as much confusion and misunderstanding as that of entropy. It is almost a synonym for disorder and yet, as a measure of the rate of dissipation of a system’s thermal energy, it can be precisely expressed in mathematical terms. It has been the bane of generations of students and is direfully associated in many minds with decline and decay, since its expression in the second law of thermodynamics (indicating that all energy will eventually dissipate into heat universally distributed and will no longer be available for the performance of useful work) implies the predestined and inevitable run-down and death of the Universe (Ibid).

Zencey (2013, p. 73) makes the notion of entropy still clearer in his article *Energy as Master Resource*. The first law of thermodynamics says that both matter and energy cannot be created or destroyed, only transformed. The second law says that when energy is transformed, its capacity to do useful work is diminished. While the total amount of energy remains the same (the

¹³⁵ Sometimes referred to as ‘negentropy’.

first law), some of it is no longer useful. This degraded energy is known as entropy, a term invented by Rudolf Clausius in 1865, who observed that “within any thermodynamically closed system, energy is conserved but entropy must increase”. Further, Albert describes the first law of thermodynamics as simply “a translation” of the principle of conservation of energy. Whereas he describes the second law – the famous one – as meaning that “entropy can never decrease as time goes forward”. Smoke spontaneously spreads from but does not collect in a cigarette. Soup cools not heats in a cool room. Chairs slow, not accelerate, when sliding on a floor. Eggs hit a rock and break, not jump from a rock and reassemble. All tends to less order, energy ultimately disperses as heat, temperatures equalise (Albert 2015, p. 3).

The US historian Henry Adams used entropy as a metaphor to interpret history at around the end of the nineteenth century, thus bringing the concept to the humanities. Kenneth Boulding writing in the 1960s, although verging on racism in his observations, thought to apply the concept to knowledge and culture:

The question of whether there is anything corresponding to entropy in the information system is a puzzling one, though of great interest. There are certainly many examples of social systems and cultures which have lost knowledge, especially in transition from one generation to the next, and in which the culture has therefore degenerated. One only has to look at the folk culture of Appalachian migrants to American cities to see a culture which started out as a fairly rich European folk culture in Elizabethan times and which seems to have lost both skills, adaptability, folk tales, songs, and almost everything that goes up to make richness and complexity in a culture, in the course of about ten generations. The American Indians on reservations provide another example of such degradation of the information and knowledge system. On the other hand, over a great part of human history, the growth of knowledge in the Earth as a whole seems to have been almost continuous (Boulding 1966, pp. 6-7).

More recently, the observation has been made that some of the stock of useful knowledge tends to decline due to technological change. Knowledge of how to handle a square rigged sailing ship is no longer needed. Nor is how to produce antibiotics rendered ineffective by overuse. At the same time, useful knowledge is replenished and advanced only due to research and invention (Matson, Clark & Andersson 2016, p. 49).

The astronomer John Barrow cites Clarke’s cautionary fable of technology and entropy *Superiority* (1951), in which an advanced civilisation is defeated in a space war by its technologically inferior opponents. The advanced group keeps developing ever more sophisticated high-tech weapons¹³⁶ that require downtime to upgrade delivery systems. In their final iteration the new systems bamboozle each other because each deployment warps space-time and gradually increases entropy so that electronics and communications are mismatched. “The more sophisticated and powerful a technology becomes, the more susceptible it is...to breakdowns and subtle malfunctions’ (Barrow 1999, p.153).

The second law of thermodynamics has been described as “the supreme” law of nature, whereby if any new theory is found to contradict it, then the new theory must collapse rather than the converse (Eddington 1928, pp. 73-75). It is only in the field of economics that its force is ignored (Zencey 2013, p. 83). Therefore, it is only when economics takes into account present ‘externalities’ such as energy return on energy invested (EROEI) can human civilisation hope to be

¹³⁶ One of which, ‘The Analyser’ contains “just short of a million vacuum tubes” (Clarke 1951).

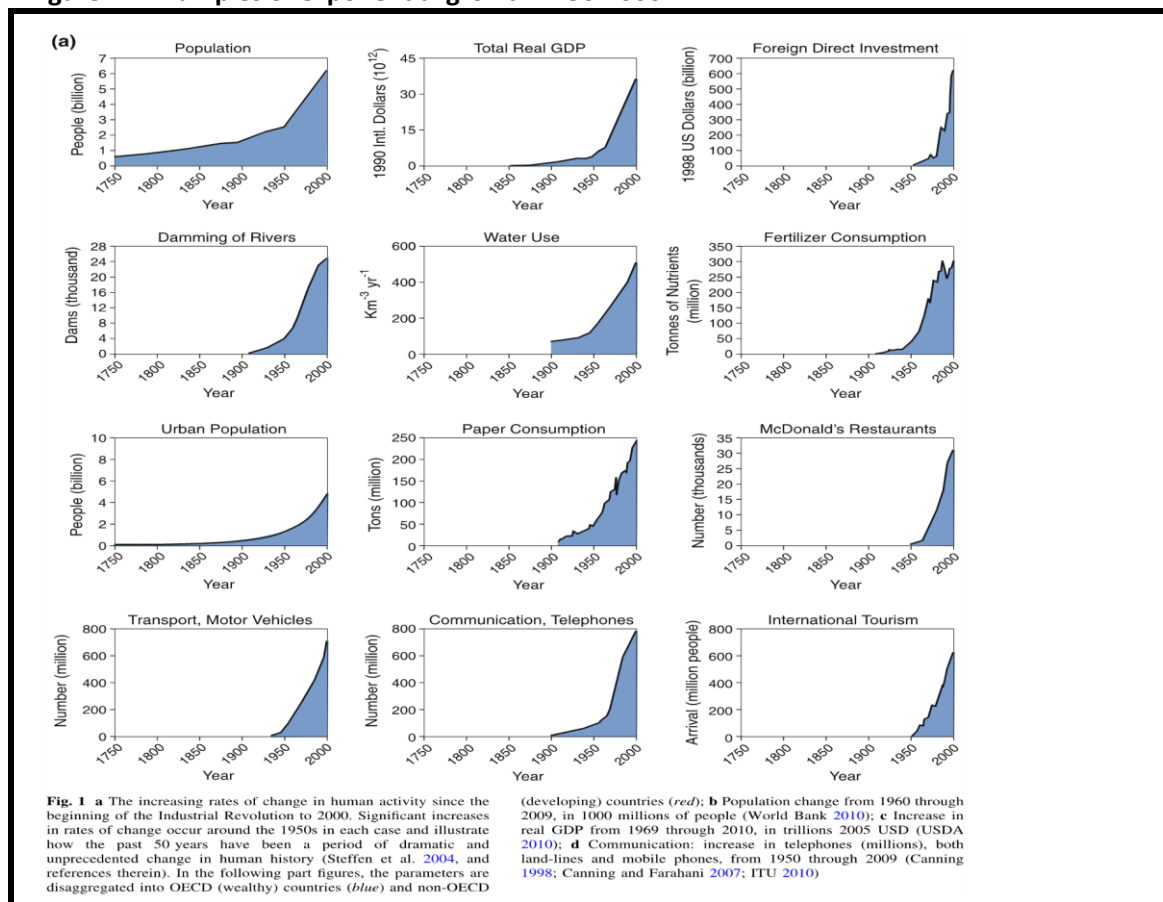
sustainable. A “bare minimum” of 3:1 EROEI would be required, while at least 5:1 EROEI would be needed to maintain “anything like what we call civilisation”. But while renewables are well above this figure, they nevertheless require a net energy input to build, as well as their infrastructure. A windmill cannot be built on *promised* energy (Ibid, p. 80; Sgouridis, Bardi & Csala 2015, p. 2).

Exponential growth

The opposite face of entropy is exponential growth, a growth built on technology, especially since the Second World War. The curves have the same shape, but are inverted. In fact, it is the converse interactions of these theoretical twins that describes our possible futures. Schmidt & Cohen (2014, p. 253), citing Kurzweil (1999), assert that technology is a continuation of evolution by other means and is itself evolutionary, “building on its own increasing order, leading to exponential growth and accelerated returns over time”.

Complementing the global environmental indicators illustration at figure 17, Steffen et al demonstrate many other examples of near exponential growth since 1750, as shown in figure 24 below. Fertilizer consumption is a little jagged and there are few rivers left to dam, but the other examples since the 1950s show alarming rates of growth. In each case, this growth is based on the amplification afforded by technology.

Figure 24. Examples of exponential growth 1750-2000



Source: Steffen et al 2011, pp. 4-6

If it is increasing entropy that ultimately limits growth (Ekins 1993, p. 272), then there are only two ways of raising that limit. One way is by exploiting the continuous flow of incoming energy available from the sun. While economic activity increases entropy by depleting resources and creating wastes, sunlight can have the opposite effect as it is both a direct energy source and the

fuel of nearly all life on Earth.¹³⁷ Physical production might then be increased, but would still be limited by the quantity of that energy available – about 1.36 kilowatts per square metre, known as the ‘solar constant’. Economic growth may still continue beyond these physical limits to the extent that it is non-physical – which it increasingly is. This is a form of ‘decoupling’¹³⁸ and depends on adding value while using fewer physical resources, such as Internet applications, recycling and provision of services rather than physical goods.

Systems theory

Systems theory was developed from different discipline perspectives by such thinkers as Ludwig von Bertalanffy, Anatol Rapoport, Talcott Parsons and Kenneth Boulding during the middle of the twentieth century. This approach involves both the physical and the social sciences, and concentrates on “the dynamics that define the characteristic functions, properties, and relationships that are internal or external to the system”, rather than so much on its components (Laslo & Krippner 1998, p. 49).

Systems theory is useful because disciplinary worldviews are increasingly fragmented. While the natural sciences have tended to synthesis through unified theories, in contrast the social sciences have tended toward relativism and to deny normative behavioural views (Ibid, p. 50), as well as being mutually incomprehensible (Boulding 1956, Snow 1959).

This concept is relevant to technology and sustainability in several ways. The technology to model Earth systems such as climate is now well-developed and involves vast numbers of sensors throughout the biosphere combined with mathematics, binary algorithms and the power of cloud computing. This approach is also applicable to the development of possible solutions to human impact. It enables evolutionary systems designers to align their simulations with the dynamics of civilisation change and with patterns of sustainable environmental development.

To an evolutionary systems designer, a ‘situation’ is a system of interconnected problems. One such situation is the evolution of economics. Another is the development of energy intensive technologies. And a third is the destruction of the Earth’s ecosystems. Humanity is in a conundrum of interconnected problems that relate to sustainability in which technology is interwoven in different ways. Their dynamics may be more important than their static components. Nevertheless, as Donella Meadows cautions, it is unwise to assume that a dynamic systems approach brings with it the prospect of all-conquering control. Rather than control, or even predict, a systems approach can help envision and bring into being, as systems can be designed and redesigned: “we can’t control systems or figure them out. But we can dance with them!” (Meadows 2008, p. 170). Systems thinking implies humility.

Ethics

The Dutch eco-philosopher, Sanne van der Hout, approaches the question of sustainable technologies from an ethical framework. She describes new technologies that increasingly mimic natural systems from the molecular level and larger — ‘*biomimetic*’ or ‘*homeo*’ technologies (van der Hout 2014, pp. 424-425) — which have been associated with a more sustainable co-existence between humans and nature. These technologies contrast with the *classical* technologies, or contrivances that are fundamentally different from natural organisms, such as the wheel and combustion engines. Classical technologies tend to

¹³⁷ Except for some life forms in deep sea volcanic vents.

¹³⁸ Mentioned in chapters 1, 4, and earlier in this chapter at p. 118.

“counteract or disturb the dynamics of nature” and are “radical simplifications” that enable some degree of human control over our environment (Ibid, p. 429).

But van der Hout disputes that biomimetic technologies are necessarily ecologically benign. In their very mimicry they may enable subtler and more pervasive ecological interference than classic brutalism. She argues that to fulfil the potential of biomimetic technologies to enhance the carrying capacity of the Earth, humanity’s predilection for luxury and consumption, for dominance over and separation from nature, must be contained by an ethic of peaceful coexistence, of humility towards nature, of being part of rather than separate from our environment. In this hope she cites Norman Cousins (1979, p. 31) who put the beginnings of a changing world view most eloquently: “What was most significant about the first lunar voyage was not that men set foot on the moon, but that they set eye on Earth”.

In this discussion, the different reach of our current technologies, whether classical or biomimetic, compared with earlier technologies is also apparent. In the ancient past, human ethics were based on the immediate – the family, the neighbour, the locality — because it was only the immediate that could be affected by our technologies. However now that technology affects the entire planetary biosphere, ethics must encompass this dimension because we are now responsible for it, both in time and space (Jonas 1984, Plumwood 1993 and 2002, Sloterdijk 2009). Thus the scale of human technological reach brings with it an ethical imperative of technological accommodation with the natural world.

Relationships

This then is where humanity is poised in its ancient and intensifying relationship with technology. How that relationship is wrought in the near future will have a major, probably decisive, impact on sustainability. But there remains a gulf between attitudes to technology and sustainability. Those who regard technology as dangerous, potentially disastrous and to be kept under firm control (Goethe, Shelley, Heidegger, Atwood, Carson, Commoner, the Huesemanns, and van der Hout) are distant from the technological transformationalists (Marx, Engels, Verne, Schumpeter, Turing, Clarke, Fuller, Ford, Richardson, Miller, Gilding, Gore and Vein), for whom nothing is impossible. Others see technology as useful in particular contexts, but that economic relationships have to change to achieve sustainability (Jevons, Schumacher, Brundtland, McGibben, Dresner, Stiglitz, Wilson, Dietz & O’Neill, the IPCC). It is this inter-relationship with economics that is unresolved. Technology may be used as a shield from the reality of increasing environmental degradation for the few, or it may be used to improve the environment for the many.

Technology’s relationship to population is already clear. Courtesy of the Industrial Revolution, technology once implied more people due to higher birthrates and lower death rates. It now implies the opposite: modern technology implies fewer people due to declining birthrates because fewer people are needed. Technology’s relationship to affluence has always been one of association. With a world connected through its latest expression it becomes possible that such affluence can be more evenly distributed as well as less destructive for the planet.

The following chapter 7 considers options to further the quest for sustainability given the foreseeable political and economic constraints upon its interconnected elements.

Chapter 7. Options

There is absolutely no inevitability as long as there is a willingness to contemplate what is happening
– Marshall McLuhan 1967

Human impact on the biosphere already approaches or has reached unsustainable levels in several areas, including the extinctions of other species, fish harvesting, de-forestation and carbon pollution of the atmosphere. Options for sustainability policy are limited. Where to act: population, affluence or technology?

While fewer people on the planet is clearly most desirable for the entire biosphere, population measures are problematic. Direct population policy such as the one child policy in China and the sterilisation program in India have resulted in inequity, demographic distortion, resentment and abuse of human rights. Even if able to be applied in Africa or other high population growth areas, similar outcomes would inevitably result. Better ways to check population are indirect – making reliable contraception accessible as well as upholding women's rights, the education of girls, encouragement of urbanisation, facilitation of migration and increasing family incomes.

Nevertheless, neither direct nor indirect approaches are at all likely to achieve global population reduction within coming decades such is the lag between action and result, that necessarily spans generations rather than the few years of a political cycle. Short of a super-pandemic, asteroid collision or nuclear war, our numbers are most likely to continue to increase until at least mid-century, and probably beyond that. There is no more lebensraum into which our society can expand. Those extra people will have to be accommodated, fed and educated within the bounds of one world.

If humanity has a future into the next or the twenty-third century, then the sort of civilisation envisaged by Arthur Clarke becomes thinkable: hundreds of millions of us rather than billions; much of the Earth re-wilded and biologically diverse. Counter-intuitively, that possibility depends on the many more people this century becoming not poorer, but more affluent, as Ricardo foresaw centuries ago affluence is inversely related to population increase. That affluence, as the SDGs suggest, includes access to modern sanitation, energy and medicines, and to education – and especially in the use of technologies that advance sustainability.

From any perspective, it is neither feasible nor desirable to set out to diminish affluence as a political platform. It is challenging, but not impossible though, to reduce inequality and it is desirable from several perspectives. The inverse nexus between income and population growth underlines the absurdity of policies that aim to reduce average levels of affluence. It might possibly aid the biosphere that more billions of us are reduced to subsistence – there might be less resource use and chemical pollution – but those same billions would resent that decline; the politics of primitivism are clearly unsaleable. Alternatively, policies that tend to reduce inequality may benefit sustainability because much of the impetus for conspicuous consumption would tend to be lessened, luxury markets for private jets and swimming pools would shrivel,¹³⁹ and especially because more people who are better off, better educated and better connected would have a stronger voice on the environmental quality that affects them.

¹³⁹ Although it might be argued that markets for more prosaic items such as air conditioners, sport utility vehicles and flat screen televisions may continue to increase as demand is driven by falling prices due to low-cost manufacturing in Asia.

Churchill's observation that capitalism tends to increase inequality has been borne out by Picketty, and considerable evidence is available that links inequality and environmental harm. But while policies that aim to reduce affluence are simply not viable, policies that tend to reduce inequality also can be extremely difficult to make stick. The fate of the *Affordable Health Care for America Act* and its later variants is a significant example here. Known as 'Obamacare', the Bill was diluted by the US Senate and passed in 2010 to the consternation of conservative Republicans. Due to be substantially wound back by 'Trumpcare' in whatever form in 2017, this major step in the reduction of inequality in the US would be undermined.

Nevertheless, elements of Kuznets' 'golden era' world of rising mass affluence and declining inequality might conceivably return on a global as well as a national scale, given determined public policies driven by the urgency of action to combat unsustainability. Such policies would include an approach to economics that measures impact on natural resources and emphasises non-material consumption rather than growth at all cost. Otherwise, unless the 'four horsemen of levelling'¹⁴⁰ revisit, inequality will inexorably rise, and the quest for sustainability will be made even harder in a world where major institutions pay only lip service to its pursuit. In any case, a rising affluence in the South implies both increased resource use and more waste in the shorter term. In the absence of significant technological development directed at these issues, sustainability will become a mirage, more elusive than an arctic fox in the snows of a Siberian winter.

Of the three main options implied by the IPAT identity, achieving a smaller global population may be feasible in the very long term, but the factor of population will continue to press probably at least until the end of this century. The denial of greater human affluence may underlie some proposals for a return to 'simplicity', but there are very few poor people in the world who would prefer to remain so. This is demonstrated not only by the dramatic increases in affluence in China and other countries of the East, but also by the increasing phenomenon of economic migration (as well as more immediate forms), whereby millions are motivated to seek the affluence and relative security of developed countries. Thus neither population nor affluence are factors that encompass practical hope for achieving a sustainable existence on this planet.

It is therefore only in technology that there may be opportunity to rein in unsustainable practices and reduce human impact, while at the same time accommodating a still rising population, growing affluence and reducing inequality. But without a different approach to technology, the practices that have already wrought mass extinction and damaged the biosphere will continue. Those practices depend upon a form of passivity, an attitude of inevitability, or the view that any innovation is good, industrial processes are progressive and that technologies give us mastery over the Earth.

Whilst humanity has been warned about technology throughout history, we have nonetheless been defined by our relationship with it and that relationship has continued to intensify. Commoner's point that technology most amplified environmental damage in the mid-twentieth century has been updated and detailed by Steffen et al in the twenty-first, and the trends are arresting. Yet technology has transformed since Commoner's time. It increasingly encompasses a much expanded range of alternatives, so much that it appears to be on the brink of a new era. In the critical energy sector, photovoltaics and other renewable sources are already viable, scalable and cheaper than established high emissions generation. In transport, electric and self-driving cars are poised to predominate. Tesla is already worth more

¹⁴⁰ Mass warfare, revolution, state failure, and pandemics -see page 87.

than Ford; India plans to ban petrol-powered cars by 2030; private urban car ownership is diminishing. High-speed rail has replaced much short-flight aviation in Europe, Japan and China.¹⁴¹ In agriculture, precision techniques and robotics minimise both inputs and waste, enabling an intensification that uses less land, and machine learning enables reliable prediction. In the chemical industry less toxic substitutes are being developed and deployed. Digital technologies enable communication networks without poles and wires, monitoring of the entire Earth, and the application of big data analytics to environmental harms.

On the demand side there are significant opportunities to cut domestic and industrial energy consumption, to reduce depletion of non-renewables and to increase demand for products from sustainable sources. This would amount to a redesign of developed economies to be more based on services rather than physical goods and to design objects for re-use rather than disposal as waste, as part of the circular economy concept.

While it is not always progressive, for sustainability to be furthered, innovation is to be encouraged and channelled in that direction. And while innovation does not depend on capitalism, capitalism is quick to exploit its fruits. Its agility and practicality cannot therefore be discarded in the quest for sustainability. Yet capitalism's stripped down neo-liberal version tends to focus on short-term returns irrespective of other merits, and enables the massing of large fortunes and political power of the few. Because it is antipathetic to sustainability, it is evidently imperative that changes to the dominant technological paradigm within capitalism are effected if human civilisation is to have a long-term future. The next question is how best to do so.

Way forward

In 1976 Marshall McLuhan wrote a manuscript with his colleague Robert Logan titled 'The Future of the Library' that remained unpublished for nearly three decades,¹⁴² delayed by McLuhan's stroke in 1979 and consequent death the following year. In it they made several observations about technology that resonate with this research. They noticed that:

We live in a complex world of high technology and intractable social problems [where] we must confront the effects of exploding population, diminishing resources, information glut and over-specialisation...We live in an era of information explosion. We are flooded by a plethora of data, yet seem unable to use our knowledge and understanding to come to terms with the difficulties facing us...The solution to any one problem exacerbates one or more of the others...Our society and technological environment has grown so complex that we find ourselves victims of a double bind where each solution creates additional problems (McLuhan & Logan 1976, p. 19).

They observe that the tradition of Western thought implies a failure to consider the impact of technology on ourselves or our environment. Technocrats are "naïve about the effects of their technologies" as Henry Ford failed to foresee the carnage of the automobile alongside the mobility benefits that it promised. In this "electric age", they say, "there can be no more monopolies of knowledge" (Ibid, p. 26), a challenge yet to be met.

With the wisdom of hindsight, this manuscript identifies aspects of our relationship with technology that appear central to our present dilemma and suggests a way forward: to interrogate the vast amount of available data to help resolve sustainability; to pay much more attention to the effects of technologies; and in doing both to fuse the quantitative with the

¹⁴¹ Including the 430km/hour Shanghai maglev train, China's high speed network is the world's largest.

¹⁴² The quotation is from an edited excerpt published with the approval of Robert Logan.

qualitative, the engineer with the artist – as was suggested in the same era by Robert Pirsig (1984 [1974]).

Alien overlords

So there is a need for stronger policy-making, especially about using technology to consume resources sustainably. Yet there remains an issue of values. The icons of contemporary new technology – algorithms, smartphones, virtual reality, artificial intelligence – associated with Silicon Valley may have vastly increased human connectivity and made fortunes for their creators, but physically and symbolically these creators and their clergy are isolated from normal life. These are our “alien overlords” – the “hoodied young software engineers who ride to work aboard luxury buses”, oblivious to all but the music in their headphones and the screen of their mobile device (Solnit, cited in Beacock 2015, para 17). The term ‘clergy’ for these aliens is appropriate more than just for its evocation of their hooded cassocks and their language of esoteric codes. Their numbers are overwhelmingly male – and young and white – which tends to result in norms and values hostile to those who are not (Corbyn 2015). It means that much technological development reflects the values of this group. Yet instead of more of the same violent gaming, drone warfare or social trivia, it is possible to imagine technologies that rely on more imaginative and creative outlooks, technologies driven by different values.

For those of us for whom the Google bus does not stop, our lives increasingly depend on technologies we do not understand, nor conceive of how we could change them. It is as if we are part of something we “cannot quite grasp, like there has been a phase shift from humans struggling to survive to humanity struggling to survive our success” (Bures 2016). Indeed, the present inevitability that we now use technologies different from each preceding generation only extends back in time about five generations. The struggle for survival for most people before the Industrial Revolution was waged with technologies unchanged for centuries – the plough, the terrace, the harness, the loom and domestic fire. Now with change seeming to compress time and our adjustment to it, there is a renewed imperative to understand how technology might serve our highest priority – sustainability.

Resource productivity

There is evidence that sustainable prosperity by mid-century is possible through “mobilising technology” and delivering incentives to reduce environmental pressure. This would amount to a decoupling of economic growth from material impact through technology. It is claimed to be demonstrable through computer modelling by economic and life scientists at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia (Hatfield-Dodds et al 2015). The Club of Rome has also undertaken extensive modelling of a new economy in which economic growth is decoupled from resource use in five European countries. Its report on the ‘circular economy’ links technology, policy reform and resource productivity to its achievement:

With a growing population, and in the developing countries a much-needed increase of per capita income (affluence), technology innovation, in combination with behaviour change – and underpinned by policy reforms – are the only options we have to bring down the environmental impacts. Luckily, there are many types of decoupling that could and should be achieved by improved technology, often complemented by behavioural change. Unfortunately, policies to promote such actions are rare. While the promotion of labour productivity has been a priority for economic policy-making in the past, resource productivity has been more or less neglected (Wijkman & Skånberg 2015 p. 8)

Resolution

As Roden (2016) observes, technology is probably “not in control of anything, but is largely out of our control”. If sustainability is to be progressed, then that control must be reasserted. But progressing sustainability is extremely complicated, involving judgments of “intergenerational ethics, science, economics, politics, and much else” to questions of “energy, agriculture, forestry, shelter, urban planning, health, livelihood, security, and the distribution of wealth within and between generations” (Orr 2006, p. 267). Ultimately, as historian Leo Marx in his *The Machine in the Garden* (1964) noticed, the resolution to the problem of technology and the environment is one not for historians or technocrats, whatever their values, but for politicians.

In this vein, the following Part Two of this dissertation concerns effecting a direction for technology that benefits a sustainable world. It considers the elements of good governance, where particular case studies show it is lacking and how it might apply to technologies in the future.

Part Two. Governing technology for sustainability

Chapter 8. Technology and governance

The essence of technology is by no means anything technological – Martin Heidegger 1953.

The ‘technology as tiger’ metaphor in the introduction highlights the need for control of its lethal power. Yet a different image, of an embrace, a dance with a duality, may be closer to our present relationship. As described in chapter 2, some technologies can both advance and degrade sustainability, depending on their targets. This dual nature is intrinsic to our bond with its many forms. Humanity’s relationship with technology is a tango with Janus without end. As technology advances, this embrace seems ever closer and the tempo ever quickens. Swept along together, humanity follows rather than leads, our partner switching between benevolence and malice. In this image, the issue is how to wrest control over the dance before calamity ensues.

This Part Two is about the governance of technology for sustainability. It addresses two related questions:

- (1) *‘What weaknesses exist, if any, in current global governance arrangements for ensuring that technology contributes to sustainability, including in its development and commercialisation?’*, and its corollary:
- (2) *‘What reforms to global governance arrangements are needed to ensure that technology contributes to sustainability, including in its development and commercialisation?’*

This chapter 8 discusses humanity’s relationship with technology and its expression through governance. It examines the dimensions of governance, and its paradigms that frame technology in relation to sustainability at state and global levels. The following chapters 9, 10 and 11 comprise a comparative analysis of three case studies of chemical herbicides, nuclear power, and robotics and artificial intelligence to identify problems with existing governance approaches. Chapter 12 summarises lessons from the case studies, and chapter 13 discusses implied reforms to technology governance and related measures to advance sustainability. The conclusion, chapter 14, is called *‘The Owl of Minerva’*, wisdom’s companion that takes flight at the end of the day (Hegel 2001 [1820], p. 20).

A form of madness

While technology is key to sustainability, how it is governed is at issue. This is because there is an ‘anything goes’ approach to technology that has both negative and positive consequences for sustainability. Not only are we using technology to ransack our world to fuel our machines and to push consumption of the superfluous, technology remains largely free of constraint, direction or accountability for the loss of sustainability it causes. As Bertrand Russell (1946, p. 482) observed, the modern attitude to technology is “a form of madness”, everything non-human is “mere raw material”; ends are not considered, only the skilfulness of the process. Yet, paradoxically, of the key factors affecting sustainability, only a changed relationship with technology holds practical hope of achieving it.

It has been said that, at least in the post-Enlightenment West, our time is always special, and much relates to technology:

Temporal narcissism demands that we must always live in the most crucial, most urgent, most dangerous, yet most opportunity-rich time in human history. Technology must always be “moving faster than ever before.” And law and policy, of course, must “not be keeping up with technology” (Vaidhyanathan 2015, para. 11).

It does seem that technology is accelerating and becoming harder to control through policy and regulation. This may be partly because the word 'technology' is increasingly assumed to mean the plethora of rapidly developing digital technologies rather than its wider meaning used here. 'Innovation' and 'disruption' are worshipped, yet much innovation is trivial and much disruption is economic; sustainability consequences are generally ignored. 'Innovation' has replaced the notion of 'progress', as perhaps it is more easily demonstrable; a diminished goal, free of annoying 'values'. If sustainable innovation is to be fostered and unsustainable innovation curtailed, new ways of governing technology are needed. Innovation may then contribute to genuine progress.

Humanity's relationship with technology is much deeper than is immediately apparent. Yet our entire past has been transformed by technology's cascade – from mastery of fire to the construction of hunting tools, to sewing and weaving, to the specialisation of Adam Smith, the industrial world of Karl Marx, to the telephone, electricity and radio, the car, the aeroplane and spacecraft, to the personal computer, the Internet and social media. Not only have we used technology to shape our world, as Engels (1940 [1876]) observed, equally humanity has been shaped by its creations, but not always in a manner obvious or benign:

Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it. But we are delivered over to it in the worst possible way when we regard it as something neutral (Heidegger 1953, p. 4).

A one-dimensional subject-object view of our relationship with technology is consistent with its ability to objectify our environment. For example, as geoengineering enters mainstream consciousness, such technologies can be seen as a threat based on extended objectification and capture of the planet:

Before geoengineering was conceivable, the Earth as a whole had to be representable as a total object, an object captured in climate models that form the epistemological basis for climate engineering...by objectifying the world as a whole, geoengineering goes beyond the mere representation of nature as 'standing reserve'; it requires us ...to see technology as a response to disorder breaking through (Hamilton 2013).

In a similar way, Pope Francis (2015, s.53) believes there is a "techno-economic paradigm" that threatens to overwhelm ecosystems and politics, based on a one-dimensional subject-object view of humanity and nature. Russell, Engels, Heidegger, Hamilton and Francis recognise the significance of our bond with technology and its capacity to alienate us from the environment. The key to governing technology for sustainability then seems to be recognition of this relationship as a mutual interaction rather than a one-way street. The consequences of technology are increasingly hard to predict, but prediction is increasingly needed, and more and more the information is available on which to base such judgements.

At the same time, it is also acknowledged that there is an extensive critical Freudian and neo-Marxist¹⁴³ body of literature concerning humanity's relationship with technology. This includes sociological works from the Frankfurt school, beginning in the 1920s, and involving such notables as Erich Fromm and Herbert Marcuse. Consistent with his own historical experience, the former was most concerned with the rise of totalitarianism and humanity's psychological "fear of freedom" (Fromm 1941), while the latter regarded technology as originally a

¹⁴³ Hegel, Kant and Weber were also significant influences on critical theory of the political economy and society.

liberating force due to its instrumental approach, but which “turns into a fetter of [human] liberation; the instrumentalisation of man” (Marcuse 1964, p. 159). Marcuse goes on to elaborate that:

Nature, scientifically comprehended and mastered, reappears in the technical apparatus of production and destruction which sustains and improves the life of the individuals [while] subordinating them to the masters of the apparatus (Ibid, p. 166).

Much of Marcuse’s central assertions were based on those of the school’s acknowledged leader, Max Horkheimer, who led the school in exile at Colombia University before reinstating it in Frankfurt after the war (Berendzen 2017). The essence of Horkheimer’s view is that the expression of technology in industrialism and its associated consumption imperative creates a human existence that is a slave to rationality (such as efficiency), and which negates any moral dimension. He also criticises Science as being overly specialised and divorced from its relationship with society (Ibid s.2.5). Overall, contemporary critical theory aims to allow people to “transform themselves on their own terms” instead of demanding their adaptation to existing conditions in order to survive (Schechter 2013, p. 133).

This present dissertation, however, goes further than the amorality of technology and its relationship with human society. As mentioned at the outset, all else in human aspiration is rendered void if our species suffers the same fate as that which has already befallen so many of our fellow creatures – extinction. And the key to that fate as well as to its avoidance is technology. Despite industrialism, efficiency imperatives and pressures to consume, humanity is self-aware. If that understanding is then applied to technology and sustainability, then such forces can be blunted so that humanity may become sustainable over the long term.

Irrespective of its power to both magnify and shrink human impact, much of the present emphasis of governance and sustainability is not on technology, but rather on where it impacts – on particular parts of the biosphere and on the global ‘earth systems’ that are represented through computer modelling. Aspects of the biosphere are beginning to be governed as part of the global commons by international agreement – especially the atmosphere in terms of pollutants and the oceans in terms of sustainable catch. However, the terrestrial lithosphere is governed more or less directly by national and local governments while agriculture, resource extraction, industrialism and human populations intersect. Without diminishing this existing geographic governance, it would seem prudent to reinforce its web by incorporating a stronger weft – the governance of critical technologies to give priority to sustainability.

Even where technology assessments do take place in respect of policy, much of the assessment undertaken is focused not on environmental sustainability, but is rather concerned with – and diffused by – wider social and economic impacts:

based on normative filters such as notions of proportionality and precaution (or as we have in the EU, the requirement to implement the precautionary principle in policy frameworks), various forms of impact analysis, such as sustainability impacts, cost-benefit analysis, environmental policy impact analysis etc., the application of particular consensual norms or prioritisation of norms (for instance that health and environment takes precedence over economic considerations) and the application of normative standards for product acceptability (Von Schomberg 2011, p. 8).

Further, there is a lot of overlap between the methods used in technology assessment, social impact assessment and environmental impact assessment. For technology assessment in the late

twentieth century, the most common methods used – often in combination – were relatively simple: expert opinion, monitoring and trend extrapolation, as well as less frequently, scenarios, qualitative modelling, non-expert opinion, quantitative modelling, checklists, and matrices in that order (Porter 1995, p. 144). At issue here is that technology assessments were not focused on their contribution to environmental sustainability, and conversely environmental impact assessments did not concentrate on the impacts of technologies. This becomes self-perpetuating, as not only do “indicators arise from values (we measure what we care about), ...[but] they create values (we care about what we measure)” (Meadows 1998, p. 2). As discussed in chapter 5, the universal reliance on GDP as an indicator of economic well-being during the past century has meant that analysis and policy is directed to its growth at the expense of other possible measures, for example.

Two decades later, the field had become rather more complicated. Singh et al (2012, pp. 296-297), for example, list 41 major composite indices that are each themselves composed of dozens of different indicators used to measure “sustainability”, or “sustainable development” of the Brundtland kind. They apply mainly to corporations, government, or processes rather than to technology directly and relate to social and economic as well as environmental sustainability. But even the “innovation, knowledge and technology” set of nine composite sustainability indices almost entirely measure the sustainability-neutral, such as the ‘monetary investment in research and development’, or the ‘number of graduates or post-graduates in the sciences’ or the ‘number of patents granted per year’, or the ‘value of high-tech exports’ (Ibid, p. 288). A single indicator of a technology’s contribution to sustainability remained elusive.

In the US, the Congressional *Office of Technology Assessment* spanned the years from 1972 until 1996, when it was closed under speaker Newt Gingrich’s ‘Contract with America’ program of expenditure cuts. Its purpose was to assess largely developing technologies so that members of Congress, who tended to be unfamiliar with such issues, could make meaningful decisions about them. However, many of its several hundred background papers and reports¹⁴⁴ concerned the social and industrial consequences of technology rather than their sustainability. This included such reports as ‘Demographic Trends and the Scientific and Engineering Workforce’ (December 1985) and ‘Displaced Homemakers: Programs and Policy’ (October 1985), which provided no suggestions for sustainability governance and were only indirectly linked to technology. Further, some of its reports may have been true, but were unhelpful on the issue of technological sustainability. Its 1994 paper, *Studies on the environmental costs of electricity*, for example, concluded “that no clear consensus exists on quantitative estimates of environmental costs of electricity, or on methodologies for making those estimates” (US Congress Office of Technology Assessment 1994, p. 2), and the paper did not suggest any.

Some decades after the closure of the Office of Technology Assessment, its functions were picked up by the US Government Accountability Office (GAO), which is independent of Congress and has a much wider field of interest than technologies. While far fewer technology assessments have been undertaken by the GAO, some do directly relate to technological sustainability, such as its 2015 assessment on ‘reducing freshwater use in hydraulic fracturing and thermoelectric power plant cooling’ (USGAO 2015). But more generally, it seems telling that a 2017 keyword search of GAO assessments shows that the word ‘sustainability’ is rarely mentioned in their titles and sub-titles. In the few cases where it is mentioned, it relates to fiscal sustainability and sustainability of nuclear weapons. The purely military term ‘sustainment’ is more common, but it bears little relationship to the quest described here, rather relating to the ability to sustain combat or other

¹⁴⁴ “In its 24 years, OTA published nearly 750 full assessments, background papers, technical memoranda, case studies, and workshop proceedings” (Office of Technology Assessment 1995 annual report, p. 7), or more than 31 per year.

missions resulting from logistics. Also, in 2012 the GAO won a satirical 'Ig Nobel' prize for literature¹⁴⁵ for a report about reports that recommends a further report (USGAO 2012), which further tends to undermine confidence in its capacity to focus.

Nevertheless, the concept of a body to undertake technology assessments influenced the establishment of similar institutions in other countries, and especially in the EU, where it became the European Parliamentary Technological Assessment (EPTA) – to which, ironically, the US GAO technology assessment group later became affiliated. Again, EPTA reports do not always concern technology and sustainability, but at least some do. There are reports on technology and waste management, on energy systems, sustainable transport and genetically modified food, for example. But the basic notion of these assessment offices implies that it is only through *government* that technology *governance* is effected, whereas this may not be so in the practical 'real world'. Alternatively, the Office of Technology Assessment pioneered the adoption of electronic reporting and distribution, taking advantage of the emerging Internet during the 1990s. It may appear trivial closer to 2020, but it meant that structured reports at least potentially oriented to technology and sustainability became universally accessible.

Governance

While the term 'governance' has been described as a 'weasel' word that is "slippery and elusive, used to obscure, not to shed light" (Bevir & Rhodes 2004, p. 133), in this context its meaning is clear. It means how we control technology in important conscious ways, rather than allowing its development unchecked by considerations of sustainability.

Crucially, 'governance' is not 'government'. Rather it is the "traditions, institutions and processes" that shape the exercise of power in making decisions of public concern (Graham, Amos & Plumptre 2003). Its emergence as a concept in the latter part of the last century, hinged on the "vast increase, in both numbers and influence, of non-state actors" as well as "the implications of technology in an age of globalisation" (Weiss 2000, p. 796). The World Bank, which is especially concerned with governance of developing states, says it is a process of interaction between state and non-state actors shaped by power. It involves government, international organisations, civil society organisations and business associations operating at various overlapping levels in "a complex network of actors and interests" (World Bank 2017b, p. 3). Importantly, governance – like technology – is systematic (Greer, Wismar & Figueras 2016, p. 3). It can apply to international society and to public and private organisations as much as to nation states and local communities. An important consideration is thus the boundaries in which it operates.

Old style command-and-control regulation was appropriate to simpler societies when governance was directly effected by government as its dominant agent. The key weakness in this style is of course that it not possible to command nor control fast changing technologies no matter how many administrators there are. Another is that controls tend to be implemented in case of rare events and exceptional cases, which unnecessarily degrades normal operations. If each step of a long process is under government control, then the process becomes ponderous; often accompanied by reams of paperwork and barriers to innovation. A more nuanced style of governance involving complex technologies is indicated to improve sustainability. On the other hand, there are fundamental sustainability issues that may not be abandoned by government. These are the issues of major, even existential risk as discussed in the case studies on nuclear power (chapter 10) and artificial intelligence (chapter 11).

¹⁴⁵ Source: Wikipedia list of Ig Nobel prize winners

As mentioned in chapter 3, there is a contrast between attempting to control waste-producing technologies at the 'end-of-the-pipe' and encouraging more sustainable technologies in the first place (such as particulate filters for combustion engines compared with electric engines that do not produce particulates). Whatever the form of governance, it is important that non-polluting technologies are preferred, as well as those that sustainably make use of renewables or substitute for non-renewables (Daly 1990). Doing so, it would appear, tends to make governance simpler and easier. A clear trend in general regulation, however, is that it is ultimately governments that set standards for outcomes, rather than for technological and industrial processes. Ends are more important than means, and if the same ends can be achieved more efficiently, then this should not be impeded. Thus for technological sustainability, such regulation would specify standards of impact, in terms of yield, substitution and assimilation rather than how they would be achieved. Whilst outcome standard-setting is logically a government role, how it concludes and enforces them can vary considerably between industries and between jurisdictions. The glyphosate case study at chapter 9 illustrates different approaches between the US and the EU for example, where in the former there is a closer relationship with industry compared with the latter, while this is different again in the case of the nuclear power industry (chapter 10) as the global French industry is particularly close to government. While the development of artificial intelligence is essentially left to Silicon Valley to determine (chapter 11), the recent struggle over what should be counted for cost-benefit analyses of US rivers and wetlands illustrates how political ideology can drive and distort outcomes (Boyle, Kotchen & Smith 2017).

None of this denies that there is a relationship between regulation and innovation. But rather, the relationship is not as straightforward as might be imagined. Strong regulation does not necessarily imply lack of innovation. It is probably more true that weak, confused and 'rule-book' regulation results in inertia and uncertainty. The key issue is the quality of the regulation. High standards appropriately enforced can enable competitive advantage built on that quality rather than commodity competition built on price. And the key issue in innovation is not its novelty, but ultimately its sustainability value. Implied political measures that would enable more sustainable technologies are discussed in 'alternative visions', the penultimate chapter 13.

Most generally, governance is about the determination and implementation of collective decisions. 'Good governance' is therefore about the quality of that decision-making and the exercise of power. Whilst expressed in different detail, there is general consensus about what it entails across several areas. The UNDP, for example, which is especially concerned with development objectives, lists nine good governance characteristics: participation, rule of law, transparency, responsiveness, consensus orientation, equity, effectiveness and efficiency, accountability, and strategic vision (UNDP 1997).

The EU condenses these to five broad categories more relevant to developed country programs: openness and transparency, participation of all stakeholders, accountability, effectiveness, and coherence (EU 2001, EU 2015). As to focus, Weiss (2000, p. 801) asserts that good governance centers on overcoming both "the unrepresentative character of governments and the inefficiency of non-market systems". Arguably, representation and efficiency remain important to its meaning.

The international Canadian *Institute on Governance* in reviewing environmental protection suggests five principles based on the UNDP formulation, which are similar to those of the EU. These are: legitimacy and voice, direction, performance, accountability and transparency, and fairness (Graham, Amos & Plumptre 2003, p. 3). Pierre & Peters (2005, pp. 3-5) writing about state-related governance say that it involves (i) articulating goals and priorities; (ii) providing

coherence and coordination; (iii) steering and implementing, directly or indirectly; and (iv) providing accountability to society. It is implied therefore that ‘good governance’ is doing these things well.

Biermann (2007) in discussing earth systems governance suggests that there are four related principles – credibility, stability, adaptiveness and inclusiveness – much due to the uncertainty and potentially extreme impacts of anthropogenic earth systems. Von Schomberg (2011, p. 16) of the European Commission advocates models of responsible innovation governance whereby actors become mutually responsive; companies identify the risks as well as the benefits of new technologies and NGOs consider the value of using new technologies as well as their potential hazards.

Ultimately, Greer, Wismar & Figueras (2016, pp. 28-29), whose focus is health policy within the EU, cite a comprehensive table linking 16 authors writing between the years 1997 to 2013 against 23 dimensions of governance,¹⁴⁶ in different contexts. The table is at figure 25 below.

Figure 25. Common dimensions of governance across literature reviewed

Dimensions of governance	Authors chronologically															
	UNDP (1997)	World Bank (1999)	WHO (2000)*	Travis et al. (2002)*	Islam (2007)	WHO (2007)	WHO/EURO (2008)*	Siddiqi et al. (2009)	Lenzi & Pettersson (2009)	Mikkelsen-Lopez et al. (2011)	Baez-Camargo & Jacobs (2011)	Kickbush & Ghechter (2012)	Council of Europe (2012)	Smith et al. (2012)	Wendt (2012)	Kaplan et al. (2013)
Control of corruption																
Democracy																
Human rights																
Ethics and integrity																
Conflict prevention																
Public good																
Rule of law																
Accountability																
Partnerships																
Formulating policy/strategic direction																
Generating information/intelligence																
Organizational adequacy/system design																
Participation and consensus																
Regulation																
Transparency																
Effectiveness																
Efficiency																
Equity																
Quality																
Responsiveness																
Sustainability																
Financial and social risk protection																
Improved health																

Source: Barbazza and Tello 2014, cited in Greer, Wismar & Figueras 2016.

From this and other information, they distil a set of five broad dimensions, which they arrange into the acronym ‘TAPIC’: transparency, accountability, participation, integrity and capacity. (Ibid, pp. 116-120). These dimensions are consistent with earlier proposals, but have three key advantages – an empirical rationale, an easily remembered acronym, and brevity. (There is also the serendipity of a near mirror of the IPAT acronym). Further, because they are universal categories and already apply to a field rife with technologies,¹⁴⁷ these elements are applicable to the governance of technology. While the authors point out that none of these dimensions is unequivocally good (too much participation can reduce efficiency, for example), they form a

¹⁴⁶ Interestingly, ‘sustainability’ appears only once: the last under ‘Council of Europe 2012’.

¹⁴⁷ That is, the health and medical field.

framework for gauging how technologies are and might be governed for sustainability. This structure is also used for the case study analyses in later chapters.

Transparency means that stakeholders and the public are informed of how and on what grounds decisions are made. Mechanisms include watchdog committees, inspectorates, and regular, clear and usable reports. Transparency mechanisms make it possible to understand an institution, identify corruption or incompetence, and ultimately rectify faults or adapt behaviours. Too much transparency can have contradictory results, however. For example, onerous freedom of information (FOI) rules can drive decision makers to conduct meetings without notes and in secret. At its best, transparency produces useful and accurate information that can be used by those who rely on or seek to influence the organisation. Ultimately, optimal transparency produces trust (Greer, Wismar & Figueras 2016, pp. 32-33).

Accountability involves both explanation and sanction. It is the relationship between an actor and a forum whereby the actor must inform of actions and explain decisions and can be sanctioned for infringements. Accountability mechanisms include contracts, rules that specify objectives and reporting mechanisms, conflict of interest policies, codes of conduct and regulation. Yet while accountability is hard to argue against in public, it can be difficult to implement and is often pursued unproductively by focussing on the relatively trivial at the expense of the important. Also, too much accountability can produce rigidity due to lack of discretion, and overly complex accountability systems can produce inefficiency. Fewer such relationships are therefore often remedial (Ibid, pp. 34-35). Accountability goes wrong when regulators are captured (Friedman 1982, p. 128) or codes of conduct ignored, which implies that more than one accountability mechanism is desirable.

Participation means that affected parties have “access to decision-making and power to give them a meaningful stake in the work of the institution” (Greer, Wismar & Figueras 2016, p. 35). If decisions are made and authority exercised without the participation of affected groups, results tend to be sub-optimal. Conversely, Fung (2006, p. 66) argues that well-structured participation improves legitimacy and ownership of implementation, justice in outcomes, and policy effectiveness through better information. Participatory mechanisms include stakeholder forums, consultations, elections or appointed representatives, choice mechanisms, advisory committees, partnerships, surveys and joint workings. However, participatory mechanisms can fail. One important issue is whether or not the purpose of participation is clear and justifiable. Another is whether the mechanism is effective in providing useful input. Creating many different participation mechanisms can create inefficiencies and delay or make difficult important decisions.

Integrity counters corruption in that it creates a trustworthy and purposeful organisation. It involves ethics, predictability and rule of law, together with well-defined roles and responsibilities aligned with clearly specified processes of representation, decision-making and enforcement. Integrity mechanisms include internal career paths that obviate officials seeking profit outside government, audit processes, personnel practices that encourage talent and remove the unsound, legislative mandates, budgets, meeting procedures and documentation. On the downside it can also mean more bureaucracy, in that procedures intended to enhance integrity can proliferate at the cost of effectiveness and efficiency. Lastly, while the benefits of well-defined organisational roles can be overstated, clarity of mission and focus on key goals cannot (Greer, Wismar & Figueras 2016, pp. 38-39). In this particular case then, mission clarity might involve ensuring that current and emerging technologies contribute to sustainability. It would also involve the identification of technologies that most jeopardise the continuation of life within the biosphere. Goals might include the development of sustainability criteria for each cluster of

technologies, the development of indices to measure progress, determining how best to phase out and substitute technologies found wanting. This critical issue is revisited in chapter 13 on alternative visions at page 203, which follows the case study summary.

Capacity generally is the capability of an organisation to undertake its mission. ‘Capacity building’ or ‘capacity development’ concern building organisational skills and abilities to accomplish ongoing objectives (e.g. UNDP 2009). Whilst relevant to governance as a general concept, in the TAPIC framework ‘capacity’ has a more specific meaning relating to policy. *Policy capacity* is the ability to develop policy in pursuit of goals aligned with resources. It is the “competencies, resources, and experience that governments and public agencies use to identify, formulate, implement, and evaluate solutions to public problems” (Forest et al 2015, p. 265). In this sense, capacity means identifying opportunities to have an impact. It includes the ability to harness data, and to understand interest group and partisan politics. It also means undertaking activities that align with its mission, as well as having the technical and political skills to participate in discussions across sectors, and to create workable regulatory structures that produce desired policy outcomes (Greer et al 2016, p. 120). Mechanisms that improve policy capacity include performance analyses to identify problems and gauge the effects of policies; process analysis to highlight legal, budgetary and systems issues; and procedures to incorporate specialist advice into policy formulation. While it is possible to have too little policy capacity, or one that lacks experience in particular areas, too much such capacity is rare, if not unheard of (Greer, Wismar & Figueras 2016, pp. 39-40).

Paradigms¹⁴⁸

While any rigid form of direct global regulation over technologies would likely tend to ossify progress towards sustainability, there are other ways to govern them. Beyond these views of humanity’s relationship with technology and the elements of governance, three key paradigms are evident in which technologies may be governed. These are the *state-first*, the *market-based* and emergent *network* models, characterised by increasing numbers of actors respectively. These paradigms are outlined below and their strengths and weaknesses assessed against the TAPIC elements.

The state-led approach

The state-led paradigm is extensive over both time and geography. It involves significant input from government and has been especially prominent in times of war, both hot and cold. But as well as collaboration on military research and development, the state has also been especially involved in energy as well as medical technologies (Harvey 2014, p. 94). At the global level, states are its singular key actors, operating in order to gain military and industrial advantage over other states.

Apart from weapons, historically the governments of industrialised countries actively invested in new technologies. The first telegraph line was US government financed in 1842, for example (Stiglitz 2001, p. xiii). State-private partnerships resulted in railroads, aviation and new energy technologies (Jenkins et al 2010, pp. 4-6). The greatest technology advances since World War I were derived from public investment in university research that became public goods, rather than via the private patent system. Penicillin was based on public research going back to Pasteur in the nineteenth century. The industrial techniques for its volume manufacture were developed at the US Drug Administration during the 1940s (Ibid).

¹⁴⁸ In the interest of variety and readability, synonyms such as ‘regime’, ‘model’ and ‘form’ are also used instead of ‘paradigm’ in this discussion.

Other state-developed technologies included radar and the digital computer during World War 2, together with satellite communications, space travel and the Internet during the Cold War. As well as such benign examples, however, nuclear bombs, ballistic missiles, and biological weapons such as Sarin gas were also developed under this paradigm. The conflicts of both world wars and the post-war intense rivalry between the US-led West and the Soviet Union were central factors in these developments.

Strengthening the patent system protecting private research in biotechnology during the latter half of the twentieth century did not cause the bio-industrial revolution, but “was rather an outcome”. The basis of the biotechnology industry had already been created by the state. Similarly, some of the superior technological achievements of the Soviet Union¹⁴⁹ resulted from concentrating public investment on innovation in certain fields, rather than from patents and other protections provided under the neoliberal regime (Draho & Braithwaite 2001, p. 213).

Geographically, the ‘Asian tiger’ economies achieved economic growth through state-led industrialisation and technological innovation, including digital technologies and robotics (Japan) mobile computing and communications (South Korea), and computer hardware (Taiwan). Such regimes attempt to gain technological comparative advantage over other states to support their own development. In China, advances in photo-voltaics combined with the huge scale of their manufacturing have led to continuing price reductions in solar energy systems around the world. Much of this expansion results from the government’s response to mounting concerns about air pollution due to coal-fired electricity generation.

However, over the past century it is in weapons technologies that the state-led approach has been most significant for sustainability governance. Biological¹⁵⁰ and chemical weapons such as the mustard gas of World War I and the Iran-Iraq war of 1980-88, and the smallpox and bubonic plague weapons developed during the Cold War are now prohibited. Cluster munitions and landmines are also prohibited, if not yet eliminated.¹⁵¹ One reason for this is that all of these weapons have uncontrollable, unsustainable effects over the longer term that involve people and animals not part of the conflict, such as the mines laid down during the 1970s conflict in Cambodia and Lao PDR (Laos). Notably, these governance measures are all simple bans. The technology is identified and it is prohibited. This suggests that state-led governance is a blunt instrument that tends to lack capacity in more complex situations.

But while nuclear weapons prohibition was the first item on the agenda of the UN General Assembly in 1946, nuclear weapons have since proliferated (Cochran 1995). This may be because nuclear weapons remain ultimate symbols of technological superiority. If so, this is in irrational contrast to other weapons, as Angela Kane, former UN High Representative for Disarmament, observed recently:

How many states today boast that they are “biological-weapon states” or “chemical-weapon states”? Who is arguing now that bubonic plague or polio are legitimate to use as weapons under any circumstance, whether in an attack or in retaliation? Who speaks of a bioweapon umbrella? (Kane 2014).

¹⁴⁹ See chapter 6 above

¹⁵⁰ US President Nixon ordered an end to the US biological weapons program in 1969.

¹⁵¹ Under the 1998 *Ottawa Treaty*, signatory countries promise not to manufacture, stockpile or use anti-personnel mines. As of 2015, it has been signed by 162 countries, notably not including China, Russia or the US.

Especially because its ultimate role is destructive, it is odd that the military appears to have escaped scrutiny in relation to sustainability. Eisenhower's famous last US presidential speech warned of the conjunction of the military, industry and technology:

In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military industrial complex. The potential for the disastrous rise of misplaced power exists and will persist...largely responsible for the sweeping changes in our industrial-military posture, has been the technological revolution during recent decades (Eisenhower 1961, s. IV).

The destruction the US military has wrought since his speech has been immense, especially in South-East Asia and the Middle East.¹⁵² While military interests and the technology of warfare have continued to be significant despite Eisenhower's warnings, nonetheless, US consumer technologies also developed in parallel. By contrast, the Soviet system of state planning over-emphasised military rather than consumer, energy or resource-efficient technologies. Non-military inventions were made but there was little incentive for them to be developed, until the failure of the system became obvious (Fukuyama 1989, p. 2; Dresner 2008, p. 151).

However, military-industrial technologies were not the only thing that Eisenhower's address warned about. Another caution anticipated the generational equity of Brundtland. It concerned sustainability, or eating the future:

As we peer into society's future, we – you and I, and our government – must avoid the impulse to live only for today, plundering, for our own ease and convenience, the precious resources of tomorrow (Eisenhower 1961, s. V).

Contemporary India offers a different take on the state-led approach to technology governance. India was a stimulus for early theorists on sustainability. The Erlichs wrote their book on overpopulation after a visit there in the 1960s (Erich 1968, p. 1, Greer 1985, p. 402, Dresner 2008, p. 25,) and the other wife-husband team, the Meadows, "intuited" the basis of *The Limits to Growth* after visiting there shortly afterward (Dresner 2008, p. 28). Then, India was a country of widespread poverty, whereas today poverty remains a major problem, but India is regarded a 'middle income' rather than a 'poor' country. Since the 1960s its population has trebled, but affluence has risen considerably more (World Bank 2016).¹⁵³

Rising affluence without loss of sustainability depends on access to low emissions energy. The election of the Bharatiya Janata Party (BJP) with Narendra Modi as Prime Minister in mid-2014 began to build on this principle. With cheap photo-voltaic panels sourced from China, Modi proposed that much of India's rural energy needs could be fulfilled by leapfrogging traditional large coal-powered electricity grids. Instead, rural households could use solar cells linked to battery storage, completely off-grid (Parkinson & Gilders 2014). This coal-free, grid-free approach was demonstrated in his home state, Gujarat, where solar power also links to the established grid in urban areas. During the election campaign, Modi emphasised his commitment to "maximum governance and minimum government" (Biswas 2014), especially relevant in a country entwined with layers of frustrating bureaucracy based on the red tape

¹⁵² Including the carpet bombing of Vietnam, Laos and Cambodia during the 1960s and 1970s, and the invasions of Iraq and Afghanistan from 2003.

¹⁵³ Despite trebling her population from about 400 million in 1961 to more than 1300 million in 2015, India's GDP per person rose five-fold in the same period. In purchasing power parity (PPP) terms, GDP per person rose nearly six-fold between 1990 and 2015, from US\$1,146 to US\$6,088 in 2015 international dollars (World Bank 2016).

detritus of the British Raj, where politics are contentious and often corrupt (Sivaram 201, p. 47).

Although also building new coal-fired and nuclear electricity plants where hundreds of millions are without access, India's energy path is different from China, which originally based its economic growth on a coal-fired energy grid. The development of both off and on-grid solar in India is due to several factors. First, the cost of coal in India from sources such as the Galilee field in Australia is rising (Buckley 2014), while the price of Chinese photovoltaics is continuing to fall. Further, India's climate would seem ideal for solar and, if decentralised, would not require the construction of a grid. Lastly, the example of air pollution in Chinese cities is a major disincentive to coal fired generation. The outstanding issue for solar is how to resolve energy storage using either batteries that are as yet unproven on a large scale, or pumped hydro storage where it is feasible. The Indian renewable energy development agency is nevertheless clear about its goals to harness the "huge potential of renewable energy resources" to supply "24 x 7 power to all but also to reduce the GHG emissions". These plans include 100 gigawatts of solar power, plus wind and hydro, as well as biomass and bagasse cogeneration by 2022 (IREDA 2016).

As suggested above, China's state capitalist economic development brought about huge increases in consumption that are evidently unsustainable, especially in the emissions of its fossil-fuelled technologies, and its impact on fishing grounds in the South China Sea.¹⁵⁴ The challenges in shifting to a more sustainable economy "remain breathtaking" (Adams 2006 p. 8), but it is evident that its state leadership is responding by, for example, encouraging photovoltaic manufacturing and anchoring measures to achieve the Paris COP 21 commitments, including closure of its dirtiest electricity plants.

France's approach to industry is based on a strong centralised state grounded in Napoleonic institutions and an elite technocratic education system. This favours big state-supported enterprises that operate on a global scale. These include *Veolia*,¹⁵⁵ which operates in waste, water and energy management, and *EDF* (Électricité de France), the world's largest electric company, which derives most of its capacity from nuclear power.¹⁵⁶ As well as energy-related institutions, the French state also developed high speed rail (*SNCF TGV*) and aero-spatial (*Air France-Industrie*, *Airbus* and *Dassault*) technologies. For these technologies, the French state-led approach indicates both opportunities and threats for sustainability governance. The opportunities centre on reach across continents, the standardisation of basic services and the capacity to determine priorities within the influence of a democratic state. Threats are the sheer size of its enterprises, possible over-reliance on nuclear power and a tendency to loosen control in favour of international market pressures.

Overall, it is typically the lack of participation in technological governance under this paradigm that stands out. The exercise of power that facilitates such large-scale technologies also depends on centralised control, whereas the capacity of the state to manage complex processes is questionable.¹⁵⁷ Where the military is involved, transparency is especially deficient, allowing such programs as nuclear weaponry to proceed in secrecy. Participation outside of these two spheres is also negligible, while accountability to democratic institutions

¹⁵⁴ China's assertion of territorial rights over the reconstructed Spratly Islands may be motivated by the decline of fishing resources closer to its coast.

¹⁵⁵ *Veolia*, formerly *Vivendi*, originated as *Compagnie Général des Eau* in 1853, the national water utility.

¹⁵⁶ France has 56 nuclear power plants due to a state development program originating in 1945 and accelerated in 1973 due to the OPEC crisis. *EDF* controls plants throughout Europe and the Americas.

¹⁵⁷ The obvious passwords *Nuclear1* and *Rad1at10n* that were offered on Russian hacking sites after being stolen from senior *EDF* employees suggests such an issue (The Times UK, 24 June 2017).

is mainly effected through budgetary measures, and is otherwise limited.

The market-based model

At the global level this paradigm involves both states and corporations acting within the world market to exploit new profitable technologies. This involves corporations funding their own research and development while the state provides subsidies and regulatory support to foster free trade and investment capital. Through international agencies such as the WTO and agreements such as TRIPS, 'mutual advantage' cooperation is encouraged, while 'winner-loser disadvantage' is rejected. Where specific technical issues risk incoherence, epistemic communities may be called on to broker technology regimes that are market compatible.

This presently dominant techno-economic paradigm is intended to promote innovation rather than sustainability. It is essentially a neoliberal approach¹⁵⁸ that supports private sector innovation with tough global-scale laws on intellectual property. These laws probably originated in 15th century Venice and were subsequently codified throughout Europe following the introduction of the printing press (Sichelman & Veneri n.d.; Mgbeoji 2003).¹⁵⁹ The current approach to intellectual property rights largely derives from nineteenth century US and German industrial practice, first internationalised with the 1883 Paris agreement (WIPO 2016) and globalised with the creation of the WTO in 1995. While in the modern era, the law increasingly lags technological innovation (Wadwa 2014), in theory private firms can roll out technological innovations quickly and profits are protected in doing so. Government is supportive rather than a technology innovator itself.

This is the system that was exploited by Thomas Edison with his remarkable series of inventions from the 1870s that defined the modern era. His industrial approach to invention at Menlo Park led to more than a thousand separate patents for devices such as the electric light, the phonograph, the motion picture camera, the microphone, the electricity grid and the car battery, all of which depended on the platform innovation of generated electricity. Influential figures helped ensure that profits were maximised. The financier-industrialist, JP Morgan, was a prominent investor who helped promote and safeguard Edison's inventions and the New York attorney, Edwin J Prindle, was a leading agent for patents to protect industrial profit. The dominant German chemical industry was similarly organised around protective patents and systematic innovation at around the same time (Draho & Braithwaite 2001, pp. 36-44).

Yet while technological governance has focused on the protection of intellectual property, both nationally and globally, its weaknesses are now that it may well discourage genuine innovation and that it is fixed on increasingly inappropriate outcomes that acknowledge no natural limits. This is the regime that so lacks sustainability governance that it gave us chlorofluorocarbons (CFCs), dichlorodiphenyltrichloroethane (DDT) and thalidomide. Each of these three examples would have fulfilled the fundamental requirements of current US patent law – essentially that the product, design or process be genuinely new and “has a useful purpose” (USPTO 2016). CFCs were useful as refrigerants, DDT was useful in eliminating malaria mosquitoes and thalidomide was useful in preventing morning sickness during pregnancy.

¹⁵⁸ 'Neoliberalism' is understood to mean the current dominant form of political economy characterised by market supremacy, free trade and corporate dominance.

¹⁵⁹ In Venice, separate laws were issued for each patent prior to a more general statute of 1474, although there were ancient claims of state reward for creativity back to the time of Aristotle (Mgbeoji 2003).

Measures enforcing intellectual property rights under this regime are part of global and regional trade agreements, including the WTO and the stillborn 12-nation Trans Pacific Partnership (TPP), which would have bound countries such as Japan, Vietnam and Australia to US-based regulation. The TPP followed years of negotiations over the application of patents in the different countries of the partnership, especially on the issue of how long each set of patents would apply, but may never enter into force.¹⁶⁰

Under the 1995 WTO agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), copyrights on software and coding, designs for integrated circuits and patents are protected.¹⁶¹ Patents protect “any inventions, whether products or processes, in all fields of technology, provided that they are new, involve an inventive step and are capable of industrial application” (TRIPS, article 27.1). The TRIPS agreement also mentions public policy “developmental and technological objectives”, as well as the special needs of least-developed countries, which may need flexible regulation to create a “viable technological base” (Ibid, preamble, para. 6). The agreement also states that “intellectual property rights should contribute to the promotion of technological innovation and to the transfer and dissemination of technology” (article 7). Nonetheless, rather than from any desire to foster innovation and transfer, it seems reasonable to conclude that developed countries and their MNCs established TRIPS in order to profit from countries that lack Western technologies (Mercurio 2014, p. 1).

The World Intellectual Property Organisation (WIPO), a UN specialised agency, is closely related to TRIPS and the WTO. A successor to the Franco-Swiss nineteenth century *United International Bureaux for the Protection of Intellectual Property*, WIPO’s role is to promote and protect intellectual property generally, not just in trade. Consistent with the TRIPS assertions, according to WIPO human progress depends on technological inventions,¹⁶² and their legal protection encourages further innovation. WIPO also claims that intellectual property protection “spurs economic growth, creates new jobs and industries, and enhances the quality and enjoyment of life” (WIPO, p. 3).

However, there is doubt that innovation was a substantial beneficiary of patent rights in history (Mgbeoji 2003), while others argue that intellectual property rights now actually constrain technological innovation. For example, a ‘think piece’ for the International Centre for Trade and Sustainable Development (ICTSD) and the World Economic Forum (WEF) argues there is a contradiction between innovation and patent protection, as patents impede diffusion and block potential gains from collaboration and competition (Mercurio 2014). It points out that patent-related legal costs amount to around US\$20 billion each year and that overlapping patents result in incremental improvement of existing technologies rather than development of new technologies. ‘Patent thickets’¹⁶³ and ‘patent trolls’¹⁶⁴ are significant hazards for those trying to innovate, such that the social and economic costs of patent protection may now outweigh their benefits:

¹⁶⁰ The TPP was signed in February 2016 after seven years of negotiations, but has not entered into force. US President Trump has since rejected its provisions.

¹⁶¹ TRIPS also protects other copyrights, trademarks, regional labels (such as wine origins), industrial designs (such as on textiles), and undisclosed commercial information.

¹⁶² As well as new cultural works.

¹⁶³ Thickets: a series of patents surrounding related inventions that can trigger litigation and act to prevent their development.

¹⁶⁴ Trolls: Those who derive profit from litigious action on patents rather than from the invention patented.

...stronger patent protection leads not to enhanced innovation or an improvement in overall welfare, but to firms protecting their interests by advocating even more protection... In so doing, firms divert resources away from R&D, and into lobbyists and lawsuits (Ibid, pp. 2-3).

Others, following their own research investigations at WIPO in Geneva, agree that intellectual property rights constrain innovation. Drahos & Braithwaite (2001, p. 2) make a case for this in their book *Information Feudalism*, in which they outline how inequality and division caused by intellectual property rights only grow stronger, and where innovation is stifled in the interests of rights holders. This occurs because rights holders increase the cost of information on which innovation depends.

In biotechnology especially, the patents market is a vehicle for commercial agglomeration rather than protection for start-ups:

Aggressive patenting of biotechnology has been a feature of the US biotech market by both public and private players. Patents over biotechnological information enhance the tradability of that information. For most small biotech firms and universities, the market for their patents is constituted by multinationals with interests in chemicals, pharmaceuticals and agriculture. For many biotech start-ups their preferred destiny is to be swallowed in one way or another by the very large fish... Patents act as a signal that they are worth swallowing (Ibid, p. 166).

‘Swallowing’ is also the business model in information technology. For example, WikiLeaks founder Julian Assange observes that Google “innovates through aggressive acquisition, then integrates what it has acquired” (Keane 2015, p. 32). But biotechnology has other ways of maintaining monopolies. During a ‘data-exclusivity period’ for biologic medicine,¹⁶⁵ manufacturers of generic copies cannot use original clinical trial data for approval to distribute their cheaper products. Many of these drugs are extremely expensive and are used for cancer treatment.¹⁶⁶ Under the TPP negotiations in 2015, the US sought 12 then eight years’ exclusivity for its corporations, still significantly longer than domestic laws in many other countries (Gleeson & Lopert 2015).

Thus the measures designed to enhance and encourage innovation under this paradigm, paradoxically tend to distort its most basic assumptions. Even if these measures were successful in promoting innovation, the sustainability of any innovation is irrelevant to the measures themselves. Sustainability is at best incidental to the corporate drive for possession, agglomeration and profit.

Within the neoliberal model, the *knowledge economy* is a concept based on technological innovation, ultimately rooted in Kondratieff and Schumpeter’s concept of technological-industrial waves. The notion emerged in the 1980s, relying on mathematical modelling by US economists, including the two Pauls – Krugman and Romer – and Robert Lucas, who worked in the new field of ‘growth economics’. The central problem as they saw it was to design an economy that would produce continuous growth and thus avoid the cyclic and structurally-induced recessions of earlier eras. Technological progress is a product of economic activity, according to this theory, whereas earlier theories regarded technology as a given, a product of non-market forces. Unlike physical objects, knowledge and technology are characterised by

¹⁶⁵ Biologic medicines: medicines made from living organisms.

¹⁶⁶ Such drugs can cost more than US\$100,000 per patient per year.

increasing returns, and it is these increasing returns that drive the process of growth (Cortright 2001, p. 3).

An important concept in the knowledge economy is that of 'rival' versus 'non-rival' goods. Rival goods are like pizza: if I eat it, you cannot, whereas non-rival goods include ideas and information that can be shared without loss. Some kinds of ideas have great economic significance. These are the 'platform' or 'meta' ideas that are the basis of other innovations and thus generate widespread new growth. For example, the Internet is a platform innovation whereas a router is not. Edison's electric generator is a platform whereas the microphone is a dependent device. The idea of 'innovation and the knowledge economy' has since entered into the popular imagination as it appears to be "self-evident", and has become virtually a "semi-religious belief system" (Coan 2012).

The importance of the knowledge economy for sustainability is that it suggests that economic growth can be dematerialised, or 'de-coupled' from resource use, especially through digital technologies and the dissemination of ideas and innovation. There are two main issues with this proposition, however. First, it presumes the existence of a technologically advanced economy in which material needs are already largely satisfied, and also it supposes a digital infrastructure for communications, for data provision and for its manipulation. The knowledge economy cannot fulfil the unmet material demand that exists in much of the world; data is inedible, nor does it supply energy. Yet it can do more than just satisfy the more ephemeral demands that emerge once basic needs are met. It can enhance and spread new knowledge. It can apply new knowledge to the global economy as much as to local ones. It can minimise human impact and help maximise resource intensity.

But such is the neoliberal paradigm that the very basis of the knowledge economy concept – the sharing of non-rival goods – can be constricted or made 'excludable' by the ownership of the data, the algorithms and the information on which it depends. For example, data from farm sensors on microclimates, soil and plant growth are uploaded in vast quantities by the US agricultural multinational John Deere and then resold as conglomerated information to others, such as seed and chemical companies. Data are also sold as discrete chunks of information back to the farmer. Farmers do not own the data from their own farms. Similarly, Facebook and Google sell their client data to advertisers, as does Microsoft,¹⁶⁷ which also dominates the personal software market and cloud data repositories. In the knowledge economy, data are as much a commodity as oil and wheat are to its industrial predecessor.

This is increasingly significant. Not only do intellectual property rights tend to constrain innovation and agglomerate market power, but as data proliferates and becomes potentially more valuable in the knowledge economy, it is owned, restricted and sold by the agglomerators – the John Deeres, the Facebooks, the Googles and the Microsofts of corporate capitalism. Governance over this aspect is weak and often years behind the data harvest and reuse techniques of major corporations. It demonstrably lacks both integrity and capacity.

The knowledge economy in its present form then, is not as attractive for sustainability as might first appear. It is rather its techniques that offer prospects to drive sustainability through technological governance. For example, the patent system itself can be trawled by algorithms that seek new combinations of ideas, new innovations that build upon existing inventions. This is a form of 'evolutionary mimicry' that designs progressively improved

¹⁶⁷ Microsoft issues a unique identifier for each client when their Windows 10 upgrade is installed, which is used to target personalised ads to clients based on their usage and demographic data (Glance 2015).

versions of devices or concepts that are tested in simulations and then the best of them selected for the next round of improvement (Marks 2015, p. 34). There is no reason to suggest that the improvements sought cannot be those that deliver sustainability.

Likewise, the application of information technology to prosaic objects of production has already enhanced their sustainability. For example, the contemporary jet passenger aircraft visually resembles its 1960s ancestor, yet it is quite different. The current version is an intelligent machine, first flown in cyberspace after its design, virtual manufacture and computer stress-testing optimised its construction. As it flies in reality, it transmits real-time information back to its manufacturers to enable further improvement and optimal maintenance (Mason 2015). The Boeing 787-9 Dreamliner, which first flew commercially in 2014, looks like the 707-120 of 1958. Yet its body is made from one-piece composite material rather than the riveted aluminium sheets of the 707 and its in-flight engine performance is constantly monitored in real time at one of several global centres owned by the three major engine manufacturers.¹⁶⁸ Such intelligent machines are thus more complex but more efficient than the visually similar but cruder technologies they replace.

In these ways, the techniques of the knowledge economy can enhance sustainability, but would be more valuable if data governance were inclusive, rather than the exclusive, low participation model that tends to be the case at present. Its capacity is lacking, and as most social media users would know, integrity and transparency are also governance qualities that are inclined to be bewildered in the corporate fine-print under this regime.

Market-based governance is also sometimes assisted by '*epistemic communities*' – associations of experts who help decision-makers define problems, identify policy solutions and assess outcomes, typically across national boundaries (Haas 1992). This aspect of governance is driven by increasing technical complexity that makes it harder for decision-makers to fully understand the issues they are dealing with. These experts typically may be academics, scientists or economists. The UN Intergovernmental Panel on Climate Change (IPCC) is a high-level example of an epistemic community.

Expertise is not always associated with wise governance, however. An extreme case of the 'cult of the expert' is embodied by Alan Greenspan, chair of the US Federal Reserve 1987-2006, who oversaw the leveraging of sub-prime mortgages that resulted in the financial crash of 2008. Greenspan's reputation was such that when he spoke at international meetings of central bankers, "the distinguished figures at the table, titans in their own fields, took notes with the eagerness of undergraduates". Both politicians and markets regarded his words as infallible – which they turned out not to be (Mallaby 2016).

Yet one notable example of epistemic technology governance with global sustainability effects occurred in an earlier era. The US Nobel laureate, Paul Berg, helped organised the 1975 *Asilomar Conference on Recombinant DNA* to discuss the regulation of new forms of biotechnology involving the manipulation of DNA between species. This technology is potentially hazardous since it involves the creation of new life forms that might escape the laboratory and multiply with unpredictable effects. The conference was to decide whether to lift a voluntary moratorium on such research and determine guidelines so that it could safely proceed (Berg 2008).

¹⁶⁸ Rolls-Royce, Pratt and Whitney and General Electric.

Berg's account is intriguing because he says it was scientists rather than politicians who were concerned about the issue. While the call for restraint was "hotly debated", the public "seemed comforted" because the cautionary call was made by the science community, and the public were kept informed of discussions. As well as scientists, conference participants included lawyers, journalists and government officials (Ibid). Although not directly mentioned, *Asilomar* was probably inspired by the international *Biological Weapons Convention* (BWC).¹⁶⁹ Berg does say, however, that the threat of government legislation helped overcome disagreement. Resolution of the issue was based on assessments of the experiments and safety measures that varied according to the degree of risk.¹⁷⁰ The conference recommendations were ultimately adopted as official US guidelines in 1976 and subsequently influenced global practice. At least according to Berg, "they have proved remarkably effective".

Now though, Berg says securing public trust for experimental biotechnologies is "much more difficult". In the 1970s such research was mainly within public institutions, whereas scientists now tend to work for corporations where commercial pressures preclude open discussion. Current political, ethical and religious conflict over values would further doom any similar consensus. The best way to secure adequate regulation of emerging technologies is for scientists from publically funded institutions to find "common cause with the wider public" as soon as possible. Once there is corporate dominance of research "it will simply be too late", he writes (Ibid).

Despite such pessimism, a similar conference met in 2015 to consider the emerging technology of genome editing, which enables heritable alteration of nuclear DNA. The conference and a subsequent study committee¹⁷¹ ultimately recommended that the technology could be used on human embryos under stringent conditions, including an 'only option' to prevent serious disease. Significantly, the study committee consulted with "patient and disability rights advocates, clinicians, scientists, ethicists, and public engagement specialists", a list considerably more controlled than in 1975. Resolution was found despite apparent tensions between democracy and corporate influence (Alta Charo & Hynes 2017).

Overall, while these examples concerned two very particular and controversial technologies, their process and results indicate that the TAPIC elements were largely fulfilled. In this paradigm, participation is at risk due to its highly technical nature. But while scientists led the process, in both cases there was significant participation of other interests. Notably, both cases were about regulating a narrow and emerging field, and were a 'one off' event. This does not necessarily mean that the same results would occur in ongoing wider technology governance where transparency is obscure and participation can tend to become exclusive.

Overall, this market-based model, tends to stress technology ownership at the expense of sustainability. Nevertheless, it is evident that some of the newer digital and geospatial technologies can enable not only resource efficiency and evolutionary improvement, but also the transparency and participation that governance of complex systems demands. At the same time, its tendency to allow exclusive data ownership threatens integrity and precludes capacity development. Epistemic groups have proven valuable for the resolution of particular technology-related issues and can add to the policy capacity of wider governance. The market-

¹⁶⁹ The *Biological Weapons Convention* opened for signature in 1972 and entered into force in 1975.

¹⁷⁰ Safety measures varied from open benches for no risk, to flow hoods, to airlocks and to negative pressure, as well as to special facilities for high risk containment.

¹⁷¹ The "Human Genome Editing" consensus study committee of the U.S. National Academy of Sciences and National Academy of Medicine (NAM).

based approach will probably increasingly rely on epistemic groups as technologies become more intricate and bring greater risk, while transparency is threatened by the same dynamic.

Network governance paradigm

Network governance has much greater participation than the other two models. Due to the many organisations involved in contemporary society, combined with shifting boundaries, complex coordination and different levels of authority, the concept of network governance emerged fairly recently in several disciplines and many of its theoretical underpinnings remain unclear (Sørensen & Torfing 2007, pp. 3-7). Emphasising cooperation and partnership rather than laissez-faire or exclusion, the approach still involves the state, often combined with international institutions, but more in orchestration roles than as direct regulators in the traditional sense (Greer, Wismar & Figueras 2016, p. 12). Corporations are also key actors as are civil society organisation, and often the interested public as well.

Its fundamental structure is informed groups of different stakeholders that share governance responsibilities within a defined sphere. Two of its prominent features are the central role of private actors combined with a voluntary, or 'soft law', rather than 'hard law' treaty approach (Abbott & Snidal 2009, pp. 505-506). While not yet applied to any particular technology, some of its characteristics are apparent in the governance of technical processes such as manufacturing supply chains and agricultural practices.

These network characteristics overlap with the *corporate social responsibility* (CSR) approach to business ethics. Both have arisen in parallel with the rise of civil society organisations, and both depend on digital communications. CSR began as a defensive response to accusations of exploitation against multinational firms that use third world workers to produce first world consumer goods. It describes situations where the firm goes beyond regulatory compliance and engages in "actions that appear to further some social good" (McWilliams, Siegel & Wright, 2005 p. 3). Although derided by an ascendant Milton Friedman in the early 1980s (Friedman 1982, p. 133), beginning with labour conditions and notions of 'fair trade', CSR has since expanded to especially include the environment in the business 'triple bottom line' of economic, social and environmental sustainability.¹⁷² Yet there is much massaging of what CSR means. Even within industries there is a proliferation of codes and the maintenance of standards beyond legal minima is voluntary and often less than transparent. But ultimately business' compliance with CSR measures depends on consumer knowledge and consumer pressure. Digital technologies can facilitate both.

The joint ILO-World Bank program, *Better Work*, is an example of network governance combined with CSR. Under this program, the compliance of apparel factories in developing countries with hundreds of labour and environmental standards¹⁷³ is accessible through its multi-lingual global database. This program involves diverse stakeholders in its governance including nine national governments, employer groups, labour unions, national and international NGOs, the UN's ILO and the Bank's International Finance Corporation, as well as the global apparel brands such as *Nike*, *Adidas* and *The Gap*. Results of factory monitoring are

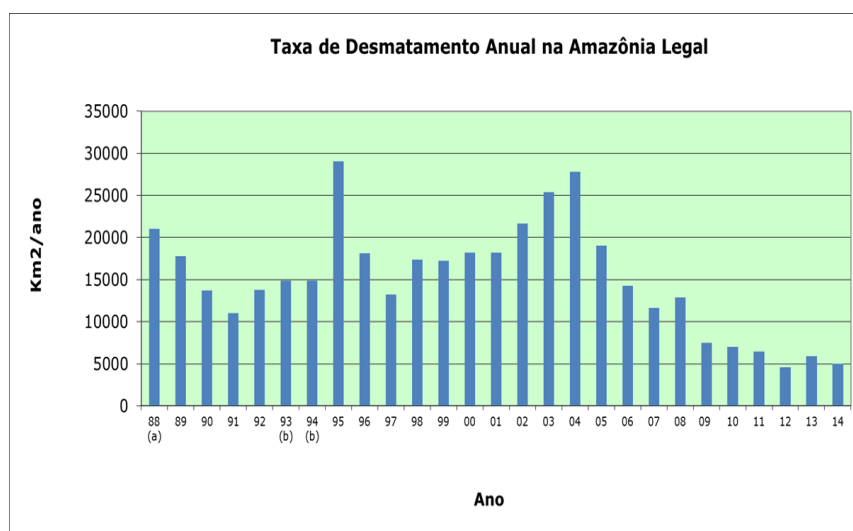
¹⁷² *Business for Social Responsibility* (BSR) is a network of more than 250 member companies, many of which are well-known global brands. Its mission is "to work with business to create a just and sustainable world...in which everyone can lead a prosperous and dignified life within the boundaries of the Earth's natural resources". The *UN Global Compact* claims over 8,000 signatory companies and aims "to work with business to...create a sustainable and inclusive global economy that delivers lasting benefits to all people, communities and markets". How much these statements are aspirational rather than tangible is a matter of debate.

¹⁷³ There are over 500 standards based on ILO Conventions and national labour law.

entered directly onto handheld tablet computers onsite and are automatically uploaded to the database for reporting and decision making. Consistent with the ‘soft law’ approach, though, much of the focus is on remediation rather than sanction (Bolwell 2015). Because command-and-control bureaucracies are incapable of governing complex societies (Offer 2005), this network approach of varied stakeholder involvement combined with digital technology is a way to make CSR and its sustainability aspirations realisable across global supply chains.

In the Amazon, two networked governance measures have helped reduce deforestation. They were both aided by the “political sea change” after the 2003 election of Lula’s¹⁷⁴ Workers’ Party and the consequent loss of influence of big landowners. The *Soy Moratorium* (*SoyM*) cut soy-related deforestation from nearly 30 per cent to only one per cent between 2006 and 2013, due to a supply-chain governance that involves farmers, buyers, NGOs and government agencies (Gibbs et al 2015, pp. 377-378). Similarly, the Amazon beef industry has been governed along these lines since 2008. A new code reduced to 50 per cent the previous unenforceable requirement that 80 per cent of land should remain forest,¹⁷⁵ and allowed landowners to trade forestation credits. Public prosecutors stopped beef wholesalers buying from illegally deforested areas and a bilateral financial arrangement with Norway bolstered political will. Technologies include satellite imagery, GPS tracking and remote sensing. Combined with a digital rural cadastre registry to track land ownership, the rate of deforestation has significantly slowed, as shown in figure 26 below (Chomitz 2015).

Figure 26. Annual deforestation rate in the Legal Amazon,¹⁷⁶ 1988-2014.



Source: Chomitz 2015.

These governance examples depend on geo-spatial and digital technologies. Yet the same enthusiasm is not apparent in applying the concept to technologies themselves. Agricultural technologies used in the Amazon for example, include synthetic fertilizers, herbicides and pesticides, as in most farming areas. Despite risks to wildlife, workers and food consumers, they are largely uncontrolled, unsustainable and based on access to cheap petroleum (Jordan 2001, pp. 161-163).

¹⁷⁴Lula: Luiz Inácio Lula da Silva, President of Brazil 2003-2011.

¹⁷⁵ The legal requirement is known as the *Reserva legal*.

¹⁷⁶ *Amazônia Legal* or ‘Legal Amazon’ is Brazil’s largest socio-geographic division, containing all nine states in the Amazon basin. The region was created in 1948 and has a population of about 24 million.

As its name suggests, one of the characteristics of this form of governance is participation – a particular virtue in areas of complexity and potential controversy. The network structure also provides both a resilience and redundancy safeguard in that capacity weaknesses in some organisations or individuals are more likely to be compensated by the capacities of other stakeholders. Transparency is also a characteristic because network governance, which necessarily involves many participants, cannot function without it. Integrity, too, is reinforced because such an approach tends to reflect the interests and views of the many, rather than the few and its actions are more visible to stakeholders. The remaining *TAPIC* characteristic, accountability, may be diluted by the numbers involved; when everyone is accountable, no-one is accountable. At the global level, accountability may also be weakened by distance from stakeholder constituencies. However, that risk is not unique to this form of governance alone. But while networks may not always be appropriate, they often work better “when there is some kind of authority in the background to give them legal force or oblige them to do their jobs well” (Greer et al 2015, p. 15).

These three governance paradigms (state-led, market-based and network) help clarify issues of how technology can be regulated and their strengths and weaknesses against the *TAPIC* criteria. The state-led approach has several weaknesses, especially in transparency, accountability and capacity. Whereas the capacity of the market-led is improved through use of epistemic communities, its tendency to restrict data ownership weakens accountability and participation. Network approaches are yet undeveloped, but indicate strengths due to its wider participation and capacity reserves.

To complete this governance overview, this chapter now highlights key aspects of the institutions and fabric of global governance that relate to sustainability and technology. This chapter ends with an introduction to the three case studies that follow separately, in which issues of their governance and sustainability are examined in more depth.

Fabric of global governance

While there are over 77,000 multinational firms operating in the global economy (Ruggie 2007, p. 823) and over 900 international environmental agreements in force (Biermann 2007, p. 335), there is little focus on technology and sustainability.

The WTO and the World Bank are part of the institutional framework of global environmental governance, as are several UN agencies. These especially include the UNEP, UNDP, UNESCO and the IAEA, as well as the IEA.¹⁷⁷ Only the two latter energy agencies relate directly to technology, if not to sustainability, whereas UNESCO mentions its carriage of technology transfer policy for development. The other two UN institutions mention ‘sustainable development’ or ‘sustainability’ as one of their objectives, but not technology at all. The Bank mentions a ‘clean technology fund’ among its functions, while WTO decisions can affect the environment indirectly.

Many global environmental interventions are modelled on the 1992 UN Framework Convention on Climate Change (UNFCCC), a pact between almost all countries that accepts commitments that are the responsibilities of individual states. The UNFCCC aims to prevent dangerous human interference with the climate system. It was developed by the International Panel on Climate Change (IPCC), itself formed by the World Meteorological Organisation (WMO) and the UNEP in 1988. The IPCC has an annual plenary of individual governments, a secretariat located within the WMO in Geneva, and several working groups with technical support on different aspects of the

¹⁷⁷ The IEA is an agency of the OECD.

issue. The UNFCCC has three sister Conventions – on biological diversity, on desertification, and on wetlands. (UNFCCC website 2017).

While global summits beginning with Stockholm in 1972 and especially including Rio in 1992 have aimed to drive consensus action for the environment, results have been mixed. Nevertheless, other governance initiatives have also been undertaken with more specific aims that involve technology. Born from frustration with the 2002 Johannesburg Earth Summit, the OECD set up the High Seas Task Force¹⁷⁸ to make practical proposals on the governance of illegal, unreported and unregulated (IUU) fishing. Its 2006 report, *Closing the Net*, recommended several important governance measures involving technologies (1, 2, 6, 7 and 9) and wider stakeholder participation (3, 8), as shown in figure 27 below:

Figure 27. Measures recommended to reduce IUU fishing

- 1 Strengthen the International **monitoring, control and surveillance** (MCS) Network.
- 2 Establish a **global information system** on high seas fishing vessels.
- 3 Promote **broadener participation** in the United Nations Fish Stocks Agreement (UNFSA) and the Food and Agriculture Organization of the United Nations (FAO) Compliance Agreement.
- 4 Promote better high seas governance by:
 - developing a **model** for improved governance by Regional Fisheries Management Organisations (RFMOs);
 - independent **review** of RFMO performance;
 - encouraging RFMOs to work more effectively through better **coordination**; and
 - supporting initiatives to bring **all unregulated** high seas fisheries under effective governance.
- 5 Adopt and promote **guidelines** on flag state performance.
- 6 Support greater use of port and trade measures by:
 - promoting the concept of responsible port states; promoting the FAO Model Port State Scheme as the international **minimum standard** for regional port state controls and supporting FAO's proposal to **develop an electronic database** of port state measures;
 - reviewing domestic port state measures to ensure they meet international minimum standards; and
 - strengthening domestic **legislation** controlling import of IUU product.
- 7 Fill critical gaps in **scientific knowledge and assessment**.
- 8 Address the **needs of developing countries**.
- 9 Promote better use of **technological solutions**.

Source: High Seas Task Force 2006

One proposal prompted by the study is to close the high seas to fishing altogether supported by satellite surveillance technologies and an expanded automatic identification system (AIS) for shipping. Modelling indicates that this would not reduce the overall catch but would improve equity between countries (Sumaila et al 2015, pp. 3-4). But while all these measures involve various technologies to improve regulation, none of them address the regulation of fishing-related technologies themselves. For example, relatively simple measures to reduce by-catch could be mandated in the interests of biodiversity, yet are not.¹⁷⁹

¹⁷⁸ The *Task Force* was a ministerial-level group of several maritime nations including Australia, Canada, Chile, Namibia, New Zealand and the UK, with the WWF, the IUCN and the Earth Institute, which formed out of frustration with the cumbersome nature of the 2002 Johannesburg Earth Summit deliberations.

¹⁷⁹ These include bright lights mounted at the front of prawn nets, devices that emit audible signals to warn dolphins and whales away from fishing nets (GWA 2011, and line weighting and streamer lines to exclude seabirds from longlines. The report does refer to the UN Fish Stocks Agreement, which

In 2001, all UN member states agreed to eight Millennium Development Goals (MDGs) for the period 2001-2015, including the last minute goal seven: *ensure environmental sustainability*. The 21 targets included ‘reversing losses of environmental resources and biodiversity’, but the MDGs tended to concentrate on measures such as poverty reduction, health and education.

However sustainability measures took more priority for the following years to 2030, when a set of 17 Sustainable Development Goals (SDGs) and 169 targets (Clark 2014) were adopted – more than twice as many goals, and eight times as many targets than the MDGs. Consistent with an analysis that helped shape the process, the much wider consultations undertaken for the SDGs were probably a factor in this conglomeration of objectives (Rippin 2013, p. 16). However, another recommendation from the analysis was the need for ‘focus’ (Ibid, p. 34), which seems to have been ignored.¹⁸⁰ To overcome this lack of focus, Secretary-General Ban Ki-moon’s 2014 report to the General Assembly framed the SDGs in six themes, as in figure 28 below:

Figure 28. Six themes of the Sustainable Development Goals

1. *dignity: to end poverty and fight inequality;*
2. *people: to ensure healthy lives, knowledge and the inclusion of women and children;*
3. *prosperity: to grow a strong, inclusive and transformative economy;*
4. *planet: to protect our ecosystems for all societies and our children;*
5. *justice: to promote safe and peaceful societies and strong institutions; and*
6. *partnership: to catalyse global solidarity for sustainable development.*

Source: UNGA 2014, p. 1.

Themes #4 and #6 are particularly relevant to sustainability as defined in this dissertation. But while this thematic overlay was not entirely successful at making the package clear, the same report did make important points about sustainability and technology, as highlighted in figure 29 below:

Figure 29. Key points on technology and sustainability from Secretary-General’s report

- s.118. **Access** to new technologies will be crucial to a sustainable world beyond 2015.
- s.119. **Environmentally sound** technologies are unevenly spread, both within and between countries. The poor in many developing countries are “locked out” from access.
- s.120. We must **phase out unsustainable technologies**.
- s.125. The UN will build an **online platform** to map technology needs and initiatives in sustainable development areas such as agriculture, cities and health, to promote networking and technical assistance and to scale up the application of clean technologies.
- s.126. Member states should build a **“technology bank”** for least developed countries (LDCs); global **intellectual property regimes** including TRIPS should contribute to sustainable development; public resources should **shift from harmful technologies** towards the sustainable development goals; and the innovation-to-market-to-public good **cycle of clean technologies** should be accelerated

Source: UNGA 2014, pp. 26-27

encourages measures to mitigate by-catch, although they are “far from fully realised” (Balton & Koehler 2006, pp. 8-9).

¹⁸⁰ Although the UN’s central agency responsible for the SDGs, the UNDP, did at the same time produce its Strategic plan 2014-2017 that centred on seven sets of outcomes, compared to the previous 35 (UNDP 2014a).

While these points do address technologies directly, much so far has proven more aspirational than concrete. Progress has been slow in the construction of the technology platform, for example, possibly due to the forest of other initiatives and targets. Indeed, while the MDGs were developed by a handful of people in a basement, the SDGs by contrast appear to have suffered from too much participation.

The 2015 Paris Agreement, however, does have clear focus. The *COP21 UN Climate Change Conference*¹⁸¹ aimed to achieve a legally binding and universal agreement on climate changing emissions from all nations. Negotiations were led by French Foreign Minister, Laurent Fabius, whose experience helped make for a positive outcome.¹⁸² The equivalent conference in Copenhagen in 2009 had foundered on the same reef that Brundtland had tried so deftly to avoid thirty years before – the issue of current versus future equity, or “progress versus the planet” (Charlton 2011). In Paris, not only was consensus reached on the draft agreement, but most countries committed to specific measures before the meeting. The biggest emitters all pledged substantial emissions cuts,¹⁸³ although the US pledge was since signalled to be revoked under the Trump administration in 2017.

Commitments under the agreement aim to limit emissions so that global warming will be no more than two degrees Celsius above pre-industrial levels and desirably less than 1.5 degrees. Targets are to be reviewed every five years. Developed countries agreed to fund \$100 billion a year for developing country investment in clean technologies and adapt infrastructure to minimise damage from climate change. A record 168 countries signed on day one, and 14 ratified immediately.¹⁸⁴ The agreement entered into force in November 2016 (Jeyaratnam et al 2016). Much of these emissions reductions depend on emissions reductions in electricity generation, transport and agriculture. Fossil-fuelled technologies are under increasing pressure as a result. Emissions trading schemes, carbon taxes and renewable energy certificates are some of the methods now used to ensure that more sustainable technologies are deployed.

In summary, the many environmental institutions and treaties tend not to address technology and sustainability as linked issues. Even the High Seas Task Force, which is essentially all about using technologies to limit unsustainable catch, fails to address technologies directly in the same aim. For the MDGs, sustainability was an afterthought, while the SDGs are a form of global governance that still lack a genuine focus on sustainability, with results yet unclear.

Against the *TAPIC* criteria, the High Seas Task Force recommendations are consistent with each element of the framework, although much depends on the capacity of states to implement and its accountabilities are vague. The MDGs were relatively successful despite the extremely narrow participation in their formulation, while the SDGs effectively fudge

¹⁸¹ This was the 21st yearly session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 11th session of the Meeting of the Parties (CMP11) to the 1997 Kyoto Protocol.

¹⁸² Fabius was France's youngest ever Prime Minister under Socialist President Mitterand 1984-1986 and Foreign Minister under Socialist President Hollande 2012-2016.

¹⁸³ The EU pledged to cut emissions by 40 per cent compared with 1990 levels by 2030. China vowed its emissions would peak by 2030. The US pledged to cut its emissions by 26-28 per cent compared with 2005 levels by 2025.

¹⁸⁴ Of the 14 countries that ratified immediately, 12 were small island states vulnerable to sea level rise (Barbados, Fiji, Granada, Maldives, Marshall Islands, Nauru, Palau, St. Lucia, Samoa, Seychelles, St. Vincent & Grenadines, and Tuvalu, all members of the *Climate Vulnerable Forum*). One was the equally vulnerable Belize, which has the world's second longest barrier reef. The other was landlocked Switzerland, which was concerned for its glaciers and snowfields, and for its own financial security.

transparency due to their complexity, possibly due to too much participation. In a related way, they also lack accountability, because responsibility for their implementation is split over several UN agencies. They do, however, at least attempt to grapple with technologies, with an effectiveness yet to be adjudged.¹⁸⁵ The Paris Agreement is a focused global pledge that puts the onus on individual states to progressively cut emissions by using more sustainable technologies. The major governance issue for Paris is singularly 'capacity', especially the political capacity of states to deliver.

Three case studies

These arrangements are all part of humanity's tango with technology. But to advance human control over the dance, it may help to know in some detail how key technologies were developed and are governed. While Part One of this dissertation approached the notion of sustainability through the IPAT structure primarily using an interdisciplinary review of available literature, this Part Two relies on a comparative case study approach. The following three chapters 9, 10 and 11 outline each case study separately: the herbicide glyphosate, electricity generation by nuclear reactor, and the development of robotics and artificial intelligence.

These particular case studies were chosen because they are all important applications of major technologies in different key industries, including chemicals, agriculture, electricity generation, manufacturing, and information technology together with its wider applications across other sectors. Glyphosate governance relates to potentially dangerous chemicals in general. The global chemical industry, built by especially German, British and US multinational corporations such as Bayer, ICI (Imperial Chemical Industries) and Dow is pervasive across the 'effortless industrialism' of the West and the East and its technologies are part of almost all the processes and products of modernity. While in this case study it relates particularly to agriculture, glyphosate also pervades our homes, the streets upon which we walk and the parks in which our children play. It has done so only since the past few decades. It is the centre of considerable controversy and relates directly to sustainability, corporate behaviour and governance.

Nuclear power is a core example of managing the risks of hazardous waste as well as ultimate disaster. It is associated with the possibility of nuclear proliferation. It has been lauded as a reliable source of 'baseload power' that has few emissions compared with other means of power generation. Yet it also brings with it issues of location – needing geological stability, the availability of large amounts of water and somewhere to store waste, as well as, preferably, distance from major population centres. Nuclear plants are also expensive and take a long time to construct. Nonetheless, as the consumption of electricity increases, there are temptations for policy-makers to turn to nuclear to assume a larger share of generation technologies. This, despite forms of governance that have demonstrable flaws.

Much of robotics and artificial intelligence governance – or lack of it – relates to the oversight of all new technologies, especially those with potential for drastic societal and environmental impacts. Yet this set of technologies is at the brink of a new industrial era, a time long-promised, where inexorable logic, data and systems are combined to release humanity from drudgery so that people can benefit from the affluence of time and creativity. Or, perhaps, a darker future looms where dull machines roam the world independently and beyond human control, or where artificial intelligences dwarf human capacity and resist the finger on their 'off' switch.

¹⁸⁵ SDG goal 14, 'Life below water', does pick up some of the High Seas Task Force concerns, as well as regulation of destructive fishing practices, at target 4.

Many other technologies such as the steam engine, the Internet, or the compact fluorescent lightbulb might also have served as case studies. However, the steam engine is well-documented as a nineteenth century platform and its relationship to sustainability is obvious and - except for electricity generation – uncontentious. The Internet is a profound and recent technology. However, its governance is largely focussed on issues of privacy rather than anything connected with sustainability, although it has considerable value in its capacity for collaboration and the dissemination of information and ideas. The compact fluorescent lightbulb produces more light from less electricity than the earlier incandescent technology, yet is a mid-step towards the still more sustainable light emitting diode (LED) form. It is interesting as an illustration of how it superseded incandescents yet itself was superseded so quickly by LEDs. Its governance is unremarkable and essentially relies on pure market forces.

The three chosen technologies – glyphosate, nuclear power and robotics and artificial intelligence – are all quite different in their underlying platforms, but are similar in that all were commercialised after World War 2. All are associated with the ‘great acceleration’ of human impact since. All three are contentious. All have had, and are having, profound environmental impacts, as well as influences on human society.

In assessing the qualities of their governance, in each case reference is made to the *TAPIC* dimensions, which cut across these examples. Other relevant lessons are also elaborated in the case study summary at chapter 12 and support a preferred governance model in the ‘alternative visions’ at chapter 13.

Chapter 9. Case study: Glyphosate

All substances are poisons; there is none which is not a poison. The right dose differentiates a poison from a remedy
— Paracelsus 1567.

Glyphosate is the world's most used herbicide, designed and used as a poison. As such it warrants close scrutiny and effective governance. But it is also associated with powerful US multinationals, with the military and with persistent controversy. Its governance involves more than just matters of fact, and it illustrates how chemicals in general are governed.

Paracelsus' observation that 'the dose makes the poison' remains fundamental to the science of toxicology. And the dose of glyphosate required to produce toxic effects in mammals is extremely high, considerably higher than substances such as caffeine and common table salt, for example. Therefore, in line with numerous research findings, it is safe to use in agriculture, especially at safety margins of many times less than toxic levels. Yet despite these reports there persists a counterbalance of investigations that identify reasons for caution, especially in its effects on non-mammals. The development of this substance illustrates how the neoliberal paradigm of patent protection, takeover and commercialisation evolves. It also shows how its governance is entangled with science, economics and politics. As a result, its status is contested along several axes.

The military

The close relationship between institutions of the military, chemical corporations and regulatory bodies is illustrated in the development of herbicides during the twentieth century. The broadleaf herbicide, 2,4 dichlorophenoxy-acetic acid (2,4-D) was developed independently by both British and US researchers during World War 2. Its purpose was to starve enemy populations through destruction of their staple crops – potatoes in Germany and rice in Japan – as well as for the destruction of "food supplies of dissident tribes" within the British empire (Perera & Thomas 1985, pp. 34-35). Whilst fortunately 2,4-D was not then cost-effective, according to an early research report it was remarkably effective in killing broadleaf plants:

one of these, 2,4 dichlorophenoxy-acetic acid [2,4-D] at a concentration of 1,000 ppm in water was applied as a spray to two 100-foot rows of apple nursery stock infested with bindweed...The sprayed plants showed change within a few hours following application (Hamner & Tukey 1944, p. 155).

Before this herbicide was developed, the control of weeds throughout history was almost entirely a matter of mechanics. Weeds were covered, pulled, ploughed, hoed or otherwise removed from the ground, largely by hand or with the animal-powered technologies.¹⁸⁶ Their removal by chemical spray therefore represented a major leap for technology and agricultural productivity.

A similar compound, 2,4,5 trichlorophenoxy-acetic acid (2,4,5-T), was also found to be likely "effective as an herbicide" at around the same time (Ibid). Manufactured by US multinationals such as Dow and Monsanto, these chemicals were widely used as weed killers from the 1950s. Their military applications were also tested during this decade — by the British in East Africa and during the 'Malayan emergency' as a defoliant. As the mixture *Agent Orange*, they were sprayed by US aircraft over crops and more than 17 per cent of Vietnam's forests in an

¹⁸⁶ Although there were limited attempts at steam and even sulphur control in the 19th Century.

attempt to reduce food and cover for the North Vietnamese Army during the Vietnam War. UN resolutions that sought to outlaw the practice were vetoed by the US and the UK, on the technical grounds that they were not direct military weapons as such. The UN General Assembly did condemn the practice in 1969, but without apparent effect (Bach 2015, s. 5).

Both these compounds kill broadleaf plants by overstimulating their growth processes. But the production of both substances is associated with dioxins, '*persistent organic pollutant*' (POPs), that contaminate the herbicides and accumulate in the bodies of animals. As top predators, humans are therefore most at risk of suffering from their effects (WHO 2014a). These include skin lesions,¹⁸⁷ as well as developmental and carcinogenic effects associated with prolonged exposure.

While both Dow and Monsanto benefited from US military contracts during the Vietnam War,¹⁸⁸ Monsanto in particular would have assumed military support for its herbicide development efforts during the 1940s and 1950s. Monsanto was directly involved in the nuclear bomb Manhattan project during the Second World War through its research director Charles Thomas,¹⁸⁹ who declined an offer to co-direct the Manhattan project with Robert Oppenheimer in New Mexico, instead preferring to stay in Ohio, working on the linked 'Dayton project' to extract polonium used in the atomic bombing of Japan (Shook & Williams 1983). According to an Army report, the nuclear program continued with Monsanto at Dayton until the mid 1980s (USDoA 2004, p. E1).

Restrictions

But as doubts grew about their effects on both people and ecosystems, these herbicides became subject to restriction and outright bans (especially on 2,4,5-T) in some jurisdictions, including in the US, Canada, Australia and parts of Europe and Asia from the 1980s onward (Cohen & Michelmore 2013). Whilst pursuing legal action in Canada against bans on 2,4-D as late as 2008 (McKenna 2011), Dow chemical finally gave up trying to defend 2,4,5-T in the 1980s after spending more than \$10 million in hearings in the US, stating that the ban was due to "public concern and public misinformation" rather than scientific reasons (Holusha 1983). Public anxiety certainly was increased by the 1976 dioxin explosion in Seveso, Italy that resulted in a toxic cloud (Bertazzi et al 1998, p. 625), cases brought by Vietnam War veterans against manufacturers in the early 1980s citing serious health effects and the 1982 evacuation and permanent closure of the town of Times Beach, Missouri¹⁹⁰ due to dioxin contamination (Holusha 1983).

All this created an opportunity for a new, hopefully less dangerous herbicide to be developed and rolled out. Enter *glyphosate*, or '*Roundup*', as it is known commercially. A chemist who worked for the small Swiss pharmaceutical company, Cilag, discovered glyphosate (N-phosphonomethyl glycine) in 1950. The discovery was not patented or reported in professional journals as Cilag did not find any pharmaceutical application. The company was taken over by the US Johnson & Johnson corporation in 1959, which subsequently sold research samples of the compound to the Stauffer chemical company and to Monsanto,

¹⁸⁷ As suffered by former Ukraine president Viktor Yushchenko who was poisoned with dioxin in 2004 (BBC News 11 December 2004).

¹⁸⁸ In fact, by 1967 supply to the US military accounted for the entire commercial production of 2,4-D and 2,4,5-T (Perera & Thomas 1985, p. 36).

¹⁸⁹ Later Monsanto President between 1951 and 1960 and Board Chairman from 1960 to 1965.

¹⁹⁰ Involving 800 families, or more than 2000 residents. The area is now a ghost town, ironically used for high-temperature disposal of dangerous chemicals.

amongst others. Stauffer first patented¹⁹¹ glyphosate as a 'chelator', which removes minerals from solutions, in 1964. A Monsanto chemist identified the plant killing properties of glyphosate in 1970 and patented it as a herbicide in 1973.¹⁹² It was first commercialised in 1974 (Dill et al 2010; Benbrook 2016).

Glyphosate works quite differently from the components of Agent Orange. While Agent Orange selectively destroys only broadleaf plants rather than narrowleaf crops such as wheat, glyphosate destroys all plants with which it comes into contact – except for plants that have been specifically engineered to be resistant to it, or have become resistant to it as a result of natural mutation. For the first few decades after commercial release therefore, glyphosate spraying was limited to places where all vegetation was to be destroyed, such as between rows in orchards and vineyards, and along rights of way such as train tracks and power lines.

But in 1996 Monsanto introduced *Roundup Ready* genetically modified crops into the US and subsequently elsewhere. These crops were specially engineered to resist the effects of glyphosate and they have since transformed the practice of agriculture throughout the world. Now, many genetically modified crops¹⁹³ are sprayed with glyphosate as a matter of course, negating the need for mechanical weed control and avoiding the limitations of earlier broadleaf herbicides (Seneff 2014). Although it was already intensifying, global agricultural use of glyphosate "mushroomed" following introduction of these genetically modified herbicide tolerant crops.¹⁹⁴ The total amount applied by farmers rose nearly 15-fold, from 51 million kilograms in 1995 to 747 million kilograms in 2014 (Benbrook 2016, p. 7) and was used in more than 130 countries by 2008 (Dill et al 2010, p. 20). As of 2015, on average more than half a kilogram of the salt was sprayed over each hectare of cropland throughout the world (Benbrook 2016, p. 1). Its normal application rate, however, is about one kilogram per hectare, and the increase in total use is mainly due to the increased area treated, so this is not especially concerning according to the eminent toxicologist, Professor Keith Solomon.¹⁹⁵

But not all of this vast tonnage of glyphosate represents profit for the company that patented it. Monsanto patents for glyphosate as a herbicide began to expire during the 1990s and many other companies began to produce it as a generic substance. Now less than a third of Monsanto's \$15 billion yearly revenue comes from glyphosate herbicide products. Most revenue comes from the patented genetically modified crops that work in synergy with glyphosate's properties as a universal weed killer (Gillam 2016). As the patents on these crop seeds would begin to expire in 2014, Monsanto since applied for a third patent on the same substance as a treatment for microbial parasitic infections such as malaria. The patent was granted in 2010.¹⁹⁶

Risks

This most recent 2010 patent has particular significance because much of the environmental risk of glyphosate turns on two concepts. One is the notion of its inhibition of an enzyme¹⁹⁷

¹⁹¹ US patent no. 3,160,362.

¹⁹² US patent no. 3977860 A, "N-phosphonomethylglycine and novel derivatives thereof useful as phytotoxicants or herbicides".

¹⁹³ Such as wheat, soybeans, barley, legumes, corn, sunflower, kiwifruit, grapes, raspberries, apples, alfalfa and sugar cane.

¹⁹⁴ Glyphosate-GMO cropping in the US and Canada has shown no advantage in yield compared with France and Germany where GMO seed is not used and pesticide use is much higher (Hakim 2016).

¹⁹⁵ Personal email communication of 22 August 2016.

¹⁹⁶ US patent no. 7771736 B2.

¹⁹⁷ The enzyme is known as 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS).

through the *shikimate pathway*,¹⁹⁸ found in plants, fungi and bacteria, but not found in animals, whereby it achieves its effect (Ibid, p. 10). Thus, in theory, glyphosate cannot be harmful to animals, including humans – except that all animals possess large numbers of gut bacteria that do have such enzymes and pathways. Adverse effects on animals are therefore possible, albeit indirect, and based on the very property relied on for its latest patent.

The other concept is the ‘surfactants’ in the weed killing spray, which are not an active ingredient themselves, but are rather intended to enhance glyphosate’s efficiency by helping it more easily penetrate foliage (Dill et al 2010, p. 10). While glyphosate itself may or may not be safe for animals and the environment, the presence of surfactant in some preparations “has been found to have greater toxicity to aquatic organisms than glyphosate (Folmar et al. 1979, cited in Dill et al 2010, p.10), although in field conditions in places such as the Ontario wetlands fell “well below” toxic concentrations observed in laboratory conditions (Ibid, p.13). Although others warn that not only are the surfactants themselves toxic, but they also enhance the toxicity of the active ingredient (Antoniou 2012, p. 9).

While chemicals may be patented, in the US all pesticides such as glyphosate also must be registered by the Environmental Protection Agency (EPA) under the ‘*Federal Insecticide, Fungicide, and Rodenticide Act*’, (US Congress 2012, s.3). Pesticides are registered providing there are no “unreasonable adverse effects on the environment” (including people) “taking into account the economic, social, and environmental costs and benefits” of its use (Ibid, s.2 (bb)). To support registration, applicants must provide appropriate research data in a form prescribed by the agency (Ibid, s. 3. (c)(F)). If the Agency is satisfied by the evidence following its own investigations and risk assessment, then applicants are permitted to distribute the product. However, the EPA assessment process is based on mathematical computer modelling, rather than its own direct investigation (EPA email of 15 September 2016,) as the following rather arcane extract from one of its guides illustrates:

The Surface Water Concentration Calculator (SWCC) estimates pesticide concentrations in water bodies that result from pesticide applications to land. The SWCC is designed to simulate the environmental concentration of a pesticide in the water column and sediment and is used for regulatory purposes by the USEPA Office of Pesticide Programs (OPP). The SWCC uses PRZM version 5.0+ (PRZM5) and the Variable Volume Water Body Model (VVWM), replacing the older PE5 shell (last updated November 2006), which used PRZM3 (Carousel et al., 2005) and EXAMS (Burns, 2003). This updated model will improve users' interactions with the program and facilitate maintenance and operation of the software (Fry et al 2014, p.2).

As this example also shows, both applicant and EPA assessments are quantitative and decidedly technical, which tends to diminish transparency. It also opens the question of whether the system might be able to be gamed, as Volkswagen were able to evade EPA standards in the emissions scandal, whereby technicians were duped by software that reacted to the precise conditions of testing (WVU 2015, Merkel 2015). Further, for ‘commercial reasons’, many of the Monsanto studies in support of glyphosate are not available for scrutiny by the broader scientific community or the public. This also tends to undermine confidence in the process, irrespective of any routine opportunity for public comment before final decisions are made.

¹⁹⁸ Although exactly “how glyphosate-induced inhibition of the shikimate pathway actually kills plants is not entirely clear” (Duke & Powles 2008, p. 320).

Agencies

The EPA was born from related areas of several agencies in 1970, and continues in “the extended shadow of Rachel Carson” (Lewis, 1985). As the largest regulatory agency in the US, the EPA is evidently the global leader in establishing chemical and other environmental impact standards, in cooperation with equivalents such as the European Environment Agency and its Chinese and Canadian counterparts, as well as global agencies such as the WHO and the FAO. The EPA can, however, be hoodwinked. In getting approval to sell a mixture of glyphosate and 2,4-D in 2011, Dow chemical told the EPA that the concoction was no more toxic than the two chemicals considered separately. It was later shown in court that Dow had told the Patent Office the opposite – that the combination of herbicides had a “synergistic effect” that increased its toxicity (Charles 2015).

However, there have been different findings from different regulators as to tolerance. As it did with DDT under its founder head, William Ruckelshaus, the EPA has the power to ban undesirable chemicals. That it has not done so with glyphosate indicates that as yet it is satisfied that the substance is, on balance, beneficial. The EU, however, is less certain: its daily chronic reference dose for human exposure is set at 3.5 times lower than the EPA rate, and a level 17 times lower has been recommended¹⁹⁹ (Benbrook 2016, p. 11). China officially regards the substance as “harmless” with no tolerance level set (Chen 2014).

The differing tolerance standards of the US and the EU may be due to culture and economics rather than science. The US, like Australia and Canada, has an agriculture based on a broad-acre efficient approach to the farming of commodities. Whereas Europe tends to smaller scale agriculture based on tradition and the desirability of maintaining a village-scale demographic. Hence industrialised agriculture in North America is more tolerant of toxicity in the name of efficiency, while in Europe, where small-scale farming is directly subsidised, farmers and consumers are more sensitive to how food is produced. China’s position is probably due to an authoritarian government most concerned with economic development. Its official position has been challenged by several hundred “Beijing food safety volunteers”, without success. Greater transparency or tighter regulation seems unlikely as it would jeopardise China’s position as the world’s largest producer of the substance. Recently Chinese authorities refused a petition to release the research on which it based glyphosate registration, made in 1988.²⁰⁰ In a familiar story, Monsanto provided the original (1985) toxicology for the registration process, but it could not be released because it contained “commercial secrets”. The Chinese government said it would “seek permission” from Monsanto to release the research, so far without apparent result (Ibid).

Of the multi-lateral agencies, the WHO is concerned only with human health. In 2015 its cancer research agency found that glyphosate is “probably carcinogenic to humans” (Guyton et al (2015, p. 491).²⁰¹ However this was contested by the European Food Safety Authority meeting under German leadership a few months later, which drew the opposite conclusion, despite several “missing” pieces of information (EFSA 2015, pp. 1-3).

In its own response to the WHO verdict, Monsanto paid consultants to convene an “expert panel” similar in size to the WHO group that with some minor caveats found “the data do not

¹⁹⁹ The EPA rate is 1.75 mg/kg/day, the current EU rate is 0.5mg/kg/day and a group of EU scientists are recommending 0.1 mg/kg/day.

²⁰⁰ Ministry of Agriculture registration number PD73-88.

²⁰¹ It was reported in *The Lancet* that 17 experts from 11 countries meeting in France as the WHO’s cancer research agency, found that glyphosate, produced as more than 750 different products, is probably carcinogenic – on a similar level to preserved meat.

support” the WHO finding. Monsanto then paid for the expert panel’s conclusions to be published in a ‘special supplement’ of a toxicology journal (Williams et al 2016, p. 16) and publicised the article. All but four of the Monsanto panel were former consultants or employees of the corporation (Monsanto 2015; Williams et al 2016, p. 3). The lead author, a former employee, had earlier published a review of glyphosate, which found that glyphosate is “practically non-toxic” (Williams et al 2000, p. 117) and so was probably a safe choice for appointment to the panel. Another safe choice had publicly attacked the WHO finding before his appointment (Arnason 2015). According to email records, “Monsanto officials discussed and debated scientists who should be considered, and shaped the project” (Hakim 2017). Further, while all of the panel appear to be experts in their fields, most are consequently at a career stage where they are probably less sensitive about reputation – aged in their 60s and 70s with the word “emeritus” often appearing in their titles. While the article was peer-reviewed, Monsanto’s involvement in the process appears less than exemplary.

Also in 2015, Monsanto filed a lawsuit against California’s health hazard assessment agency for listing the substance as a carcinogen²⁰² following the WHO finding (Plume 2016), which at the time of writing is unresolved. In a further contradiction, the EPA had subsequently found glyphosate to be not likely carcinogenic on preliminary review, with a final assessment scheduled for 2017 (Huffstutter 2016). But as part of the legal process, the federal court considering glyphosate’s health effects unsealed internal Monsanto emails and other emails between Monsanto and the EPA. The Monsanto emails showed that an EPA deputy director had vowed “to beat back” an attempt by the Department of Health and Human Services to conduct its own glyphosate review. In another email a Monsanto executive told other company officials that they could hire academics to put their names on papers about glyphosate that were actually ghost written by Monsanto. The company has denied the practice (Hakim 2017).

With the FAO, the WHO has also published regulatory guidelines for states, especially developing countries, on the management of pesticides, which are not substance-specific (FAO-WHO 2014). However, the FAO-WHO *Codex Alimentarius*, does list individual pesticides and shows maximum limits for glyphosate residues in 31 different foodstuffs and fodder.²⁰³ One of its most important functions according to its own website is to limit tighter standards by importing countries that would form a restraint on trade; the *Codex* is an instrument under the WTO’s free trade provisions.²⁰⁴ In effect, it puts a limit on standards higher than its own assessments. The range of food residues for glyphosate covered by the *Codex* is far narrower than the EPA (31 against 158), the classification descriptions are not consistent between the two and, as with dosage tolerances, food residue limits are different in several cases. In the *Codex*, meat from both mammals²⁰⁵ and poultry have a maximum glyphosate residue of 0.05 parts per million, whereas the equivalent EPA levels are 5.0 and 0.10.

Use

How glyphosate is used also differs. Toxicology studies typically refer to the mixing and use of glyphosate compounds “in accordance with the label” instructions. But even if most US farmers are literate and observe the instructions, some may not. Further, as the compound is

²⁰² The California listing results from ‘*Proposition 65*’, a direct voter initiative that was carried overwhelmingly in 1986, which requires carcinogenic substances to be so labelled.

²⁰³ Including alfalfa fodder, meat, milk, soy and wheat (WHO-FAO 2016).

²⁰⁴ “WTO members that wish to apply stricter food safety measures than those set by Codex may be required to justify these measures scientifically” (WHO-FAO 2016: About Codex). The Codex originated in the early 1960s and was included in WTO provisions during the Uruguay round (1986-1994).

²⁰⁵ Mammals other than marine mammals, such as pigs, horse, goat, cattle.

used in over 130 countries, many people involved may not even be able to read the instructions, let alone take care in its handling. Further, in industrialised countries, glyphosate is typically sprayed from a tractor towed boom. But North American farmers tend to be enclosed in air conditioned cabs, unlike farmers in South America, for example, who are typically open to the elements and are therefore exposed to glyphosate drift. These risks have been ignored in some regulatory studies, as have other adverse findings in Ecuador and Argentina (Antoniou 2012, p. 9).

There are some further concerns. There is evidence that any research critical of glyphosate is subject to a coordinated academic censure: many of the critics are in the employ of Monsanto or benefit from its funding and therefore are conflicted and cannot be free of apprehended bias (Séralini et al 2014, pp. 2-3). Also, one public relations counter to negative publicity is 'GMO Answers', a website that responds to individual concerns about genetically modified organisms and glyphosate. According to the site itself, "GMO Answers is funded by the members of the 'Council for Biotechnology Information'", which includes BASF, Bayer, Dow AgroSciences, DuPont, Monsanto and Syngenta. A random sample of answers to concerns in August 2016 indicated that most of the "qualified experts" answering were in fact employees of Monsanto or the Council.

Beyond the Anglosphere, where there is less leverage from such corporations, more critical studies of the effects of glyphosate have emerged. In Sweden in 2008, it was reported that glyphosate exposure is a risk factor for non-Hodgkin lymphoma. In Argentina there was controversy in 2009 after a scientist reported a high incidence of human birth defects and cancers in those living near crop-spraying areas, as well as genetic malformations in amphibians (Gammon 2009).

A particular example of how the science surrounding glyphosate is contested is the French molecular biologist, Gilles-Éric Séralini cited above, whose 2012 study of the effects of genetically modified corn that had been sprayed with glyphosate drew a wave of criticism, including from reviewers who were associated with Monsanto. Séralini's paper,²⁰⁶ which found that rats fed on the corn tended to develop tumours, was subsequently withdrawn by its original 2012 publisher following criticism of its methods. However, a revised version was re-published in different open-access journals two years later and reported in the prestigious *Nature*, which tended to increase publicity of its findings and the controversy it stirred (Casassus 2014).

Later biological research at the same institution²⁰⁷ found major discrepancies between the official view of glyphosate and the reality of its formulation:

It is commonly believed that Roundup is among the safest pesticides...Despite its reputation, Roundup was by far the most toxic among the herbicides and insecticides tested. This inconsistency between scientific fact and industrial claim may be attributed to huge economic interests, which have been found to falsify health risk assessments and delay health policy decisions (Mesnage et al. 2014).

The Anglo-Brazilian paper cited above on the effect of glyphosate on embryos (Antoniou et al 2012) found that German and EU approval of glyphosate levels was partly based on "unpublished industry-sponsored studies", and "minimised" earlier findings of malformed

²⁰⁶ The paper, 'Long term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize', was published in *Food and Chemical Toxicology* in September 2012.

²⁰⁷ The University of Caen, Normandy.

fetuses allowing potentially unsafe acceptable daily intakes of the substance. They further cite several studies showing a link between birth defects and miscarriage in Canada and Argentina from glyphosate spray exposure. Based on these sorts of studies, glyphosate is now banned in several countries — Norway, Denmark, Sweden, Sri Lanka, El Salvador, Brazil, and India. Unlike the US EPA registration system, in these countries there is significant distance between industry experts and government regulators who decide what is or is not toxic (Davis 2016).

By contrast, the EPA released a report on 29 June 2015 that concluded that glyphosate was not an endocrine disruptor (USEPA 2015). However, a popular critical review points out that much of the evidence considered was studies funded by Monsanto and other companies. Of the five independent studies considered, three were cautionary, but were outweighed by industry provided evidence (Strauss 2015). Interestingly, the EPA report does refer to one study that raised concerns about the adverse effects of a surfactant commonly used with glyphosate (USEPA 2015, p. 60), but this is not mentioned in the summary findings.

Overall, one of the most comprehensive reviews of the substance, Székács & Darvas' (2012) *'Forty Years with Glyphosate'*, which refers to almost 200 earlier studies, found that glyphosate formulations can increase fungal infection of soy crops, are toxic to amphibians and can produce tumours in both amphibians and birds at relatively low concentrations. According to the review, glyphosate can also cause malformations and developmental disorders in a range of species (Ibid, pp. 262-266). Importantly, the article further puts a figure on Monsanto's unpublished studies: "of 180 research reports of Monsanto, 150 are not public, or have never been presented to the scientific community" (Ibid, p. 264).

Cuhra et al's (2016) Norwegian review study concludes that glyphosate regulation should be tightened, not relaxed as has happened in the US, because the industry is too close to regulators, there is evidence of fraudulent practice and many research studies do not assess its effects in its commercial formulations. They found that more than 62,000 articles²⁰⁸ on "glyphosate" were published between 1965 and 2014, with about 20,000 concerning "safety" or "risk".²⁰⁹

Similar to the US, European corporations involved with glyphosate have a website (www.glyphosate.eu) that publishes positive articles and 'fact sheets' about the substance in English, German, Spanish and French. One such fact sheet²¹⁰ does admit that spray surfactants "could be harmful to aquatic organisms by impairing the integrity of cellular membranes". Reassuringly, it says that risks are "mild or negligible if glyphosate is used in accordance with label instructions and good agricultural practices". Less comforting is the label instruction for Roundup that it should not be used in or near freshwater to protect amphibians and other wildlife. Confusingly though, the Australian 11-page guide to Roundup for example, similarly says it should not be used near freshwater (Nufarm 2013, p. 1) but also refers to its use "for weeds in aquatic situations" as long as "the entry of spray into water" is minimised (Ibid, p.7). On the one hand it is not to be used in or near freshwater, on the other it can be — to kill aquatic weeds. Both cannot be true.

Influence

It has been further suggested that the glyphosate industry influences government policy and safety regulations in favour of its products. This is shown in figure 30 below. Because

²⁰⁸ These were peer-reviewed scientific articles and related posts such as technical reports and patent documents found on Google scholar.

²⁰⁹ Similar results were obtained by the author of this dissertation in October 2016.

²¹⁰ *Glyphosate the environment and wildlife faqs*, p. 3.

glyphosate has been applied in increasing amounts only days before harvest especially in the North America, there are now much higher residues in the harvested crops than previously.²¹¹ After Monsanto and others requested substantial increases in glyphosate tolerance levels for these crops, typically they were granted. The table shows that in the most extreme examples, alfalfa hay and silage tolerances have increased by 2000 times between 1993 and 2015, from 0.2 to 400 parts per million.

Figure 30. Changes in glyphosate tolerances, US. Environmental Protection Agency levels, parts per million

	1993	1999	2012	2015
Soybeans (grain)	20	20	20	40
Soybeans (hay)	15	200	200	100 ²¹²
Soybeans (forage)	15	100	100	100
Maize (corn grain)	0.1	0.1	5	5
Maize (corn stover)	NT	NT	6	100
Maize (sweetcorn)	0.2	0.2	3.5	3.5
Oats (grain)	0.1	0.1	0.1	30
Wheat (grain)	0.1	5	5	30
Wheat (straw)	0.1	85	85	100
Edible beans	0.2	0.2	5	5
Alfalfa (dry hay)	0.2	200	200	400
Alfalfa (silage)	0.2	75	75	400

Source: Benbrook 2016, p. 9, table 7

Large tolerance increases were also granted in Europe on application by Monsanto in 2012, after it was found that imported Canadian lentils showed high residual levels of glyphosate. The existing residue limit for glyphosate in lentils was then 0.1 mg/kg and the application recommended raising it to at least 10 mg/kg — a factor of at least 100. The EU acceded to the 10mg/kg limit in May of the same year (EU 2012, L 135/15; Cuhra et al 2015, p. 9).

Despite increasing concerns, as late as 2008 one paper by leading plant biologists described glyphosate as “very toxicologically and environmentally safe” and a “virtually ideal herbicide” (Duke & Powles 2008, p. 319). Although eight years later Professor Duke was wary when asked if he still held the same views, instead referring the question to a toxicologist.²¹³ But irrespective of its toxicity, these authors caution that there are sustainability challenges in the very success of the world’s number one herbicide because “glyphosate-resistant weeds will emerge” so that there needs to be less reliance on glyphosate and more on new chemical, “mechanical and precision application technologies” (Ibid, p. 324). Professor Duke advised in 2016 that weed resistance “has grown much worse since our paper was published.”

But as far as its toxic effects are concerned, he observes that “papers more critical of glyphosate than Séralini’s...[are] mostly in predatory (‘pay to play’) journals”, whereas there are many studies showing ‘no effect’ – despite the difficulty of getting a journal to publish a ‘no effect’ paper. Duke further comments that “unfortunately, this topic is politically charged, with many unqualified people taking sides. That is not the way science should be done”.²¹⁴ This issue is one that lingers across its governance. For example, a 2015 article in a Canadian

²¹¹ In an email of 3 August 2016, Dr Benbrook advised that the three food varieties shown under ‘Soybeans’ are consistent with terms used by the Environmental Protection Agency.

²¹² Note: as at September 2016, the EPA showed this as 200 parts per million.

²¹³ Personal email of 20 August 2016.

²¹⁴ Ibid

agricultural newspaper ‘Toxicologist pans UN glyphosate report’ drew more than 30 pages of online comments reflecting divergent views of the substance and its effects (Arnason 2015). Indeed, this is a matter of politics as much as science.

Bearing in mind the old joke about Russian roulette whereby five out of six scientists declare the practice safe, there are patterns apparent in the politics. On the basis of the information reviewed for this assessment, the axes of contention are speculated in figure 31 below:

Figure 31. Glyphosate: axes of contention

More tolerant	Axis	Less tolerant
Industry (profit)	Motivation	NGOs (health and environment)
Toxicologists, plant biologists	Discipline	Molecular biologists, entomologists
Anglophone	Culture	Francophone
US, China	Geography	Europe, South America
Nation states	Scale	UN agencies, EU

Industry tends to support more tolerant glyphosate standards because it is good for profit, whereas civil society represented by NGOs is more concerned about health and the environment. Toxicologists, who concentrate on “active ingredients” and by-the-label instructions (and who are often employed by chemical companies) tend to support industry, whereas more independent entomologists tend to be concerned about its effects on insects, especially pollinators. Anglophones, who commercialised the substance and have large scale agriculture, tend to be more tolerant than say francophones, who are more suspicious of genetically modified crops and favour smaller scale intensive agriculture. The large producer states – the US and China – tend to be more tolerant than the consumers of Europe and South America, while national environment agencies tend to be more tolerant of glyphosate than multilateral agencies of the UN and EU that are more removed from commercial pressures.

Agreements

Apart from the WHO and FAO institutional involvement described above, there are several related multilateral agreements relevant to the sustainability of chemical technologies. These include the Montreal Protocol (adopted 1987) banning ozone-depleting substances, the Basel Convention (1989) restricting the transboundary disposal of hazardous waste, the Rotterdam Convention (1998) restricting trade in hazardous chemicals and the Stockholm Convention (2001) that limits persistent organic pollutants, such as dioxins. There is also the Minamata Convention (2013) on the control of mercury. These Conventions typically involve a global secretariat, a committee of scientific experts and regular meetings of the signatories, each known as a ‘conference of the parties’. Signatories can be states as well as regional groupings such as the EU.

All of these measures resulted from major disasters, such as the emergence of an ‘ozone hole’ in the early 1980s, the dumping of thousands of tons of US industrial waste on a beach in Haiti in 1986 (Avril 2002), and thousands of deaths in Japan and Iraq between the 1950s and 1970s due to mercury poisoning. None, however, capture glyphosate within their net. Any future Convention involving glyphosate would only arise due to a major international calamity, which appears unlikely. It is therefore more probable that the present mixed voluntarist regime plus industrialised state regulation will continue.

‘Responsible Care’ is a form of voluntary private governance in this industry, which began in Canada in 1985 and now claims most of the world’s chemical production. As such, it does at least theoretically encompass glyphosate. It is essentially a commitment to a program of

continuous improvement in both workplace safety and environmental impact. Its leading safety indicators²¹⁵ are the number of worker fatalities (about 40 per year globally) and the 'lost workday case rate' (about four days per year per 'case'). Its environmental indicators are emissions of various gases (NO_x, SO₂, CO₂ and 'chemical oxygen demand',²¹⁶) energy and water consumption, as well as 'distribution incidents', all compared with production. 'Distribution incidents' are cases of spillage of dangerous chemicals (around 1800 per year).

Its origins were not entirely altruistic: "there is no question that the threat of regulation served as a major incentive for the development of the program" (Moffet et al 2004, p. 204). Also its indicators relate to only a few impacts of its technologies – the ones easy to measure; indicators of environmental accumulation and toxicity, for example, are missing. It lacks consumer involvement and its coverage is not universal. Yet it does link with other elements of global governance such as the UN Global Compact and the International Standard Organisation's 14000 series on environmental impact management.²¹⁷ *Responsible Care* also acknowledges the UN Sustainable Development Goals (2015-2030), especially goal 6 (clean water and sanitation) and goal 12 (responsible production and consumption) that target waste reduction and chemical pollution in general, especially as they affect water supplies -- an area pertinent to glyphosate and its effects on amphibians.

The *Strategic Approach to International Chemicals Management* (SAICM) is the intergovernmental response to increasing chemical risk. It is a 'policy framework' to foster the sound management of chemicals, and unlike the above initiatives, focuses directly on the chemical technologies concerned. Developed in 2006, it concedes one of the challenges is assessing the risks (and opportunities) "associated with more than 100,000 different chemicals". While participation is again voluntary, it does encourage better regulation from its stakeholders, which are unusually wide-ranging and include nearly 300 "governments, regional organisations, intergovernmental organisations, plus non-government organisations, from industry, consumers, farmers, transporters, producers, researchers, suppliers, waste and disposal handlers, and unions"²¹⁸ (UNEP 2015, p. 5 and p. 1). A child of the UNEP and WHO as well as other UN agencies such as the ILO and FAO, it includes a governance strategy that embraces integration with development programs, together with stronger regulation and compliance measures. Much of it is focussed on the developing world and it remains relatively underfunded.²¹⁹ The SAICM also continues to face serious obstacles. At its recent meeting in Brasilia, some stakeholders, including industry and developed country governments, argued for concentrating on the development of a solid chemical regulatory regime and building technical capacity. A proposal for a science-policy interface for chemicals and waste similar to the IPCC or the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) was rejected. Yet to be agreed too, is how to practically implement the strategy (ENB 2017, p. 12).

²¹⁵ Indicators are taken from its 2015 Responsible Care status report: <<https://www.icca-chem.org/wp-content/uploads/2015/09/2015-Responsible-Care-Status-Report.pdf>>.

²¹⁶ Presumably not an emission, but rather oxygen used in chemical production.

²¹⁷ The 14000 series are essentially sets of checkboxes that guide and evidence that an enterprise conforms with a standard of environmental management, rather than a set of environmental standards that must be met. A key change in 2015 was that enterprises are encouraged to think of environmental impact over the entire life cycle of their product, from resource extraction to use and disposal, not just at production and sale. It appears to be a more extensive approach than Responsible Care, is complementary to it and is likewise voluntary.

²¹⁸ Comprising 175 governments represented by environment or foreign affairs ministries, and 17 by health, labour or agriculture ministries, with 85 NGOs from industry and civil society.

²¹⁹ SAICM has "supported projects worth more than US\$110 million in more than 100 developing countries" (UNEP 2015, p. 02)

At the US national level though, the professional body for the chemical industry has adopted a set of principles called 'green chemistry'. These are summarised at figure 32 below:

Figure 32. Twelve principles of green chemistry

1. Prevention. *It is better to prevent waste than to treat or clean up waste after it has been created.*
2. Atom economy. *Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.*
3. Less hazardous chemical syntheses. *Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.*
4. Designing safer chemicals. *Chemical products should be designed to affect [sic] their desired function while minimizing their toxicity.*
5. Safer solvents and auxiliaries. *The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.*
6. Design for energy efficiency. *Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.*
7. Use of renewable feedstocks. *A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.*
8. Reduce derivatives. *Unnecessary derivatization (use of blocking groups, protection or deprotection, temporary modification of physical or chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.*
9. Catalysis. *Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.*
10. Design for degradation. *Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.*
11. Real-time analysis for pollution prevention. *Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.*
12. Inherently safer chemistry for accident prevention. *Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.*

Source: American Chemical Society 2017; original source cited as Anastas & Warner, 1998, p. 30

These principles are a summary and can be 'drilled down' for greater detail on the society's site. Their adoption followed several major chemical disasters and the resultant introduction of the US Pollution Prevent Act of 1990. Europe and the OECD were involved in complementary initiatives during the same era (ACS 2017). If producers and regulators implemented such principles, it would mark a big step towards a sustainable chemical industry.

Weaknesses

On balance then, there are several weaknesses evident in the governance of glyphosate, all of which militate against sustainability. They also tend to undermine the credibility of the wider chemical industry, as do the dangers of substances including persistent organic pollutants (POPs) such as DDT, dieldrin and dioxins that are banned in many jurisdictions (Ritter et al 1997).

First, the military-industrial relationship involved in its development undermines public confidence because it is associated with secrecy, destruction and the use of force. Also US multinationals such as Monsanto have opposed unfavourable research and regulation concerning the herbicide. Monsanto has been particularly aggressive in attacking adverse findings and even pays academic toxicologists to publically support its cause. While its human toxicology nevertheless still appears relatively benign, evidence for glyphosate's effects on

other life forms, especially aquatic animals, appears increasingly less favourable. Further, a technical approach to its control has resulted in acceptance of research based on an unjustified adherence to instructions on the label. In any case, its instructions are contradictory in relation to its use around water. There is thus a participation deficit in its governance.

The continuing controversy over glyphosate and its increasing use world-wide are linked issues. Much of the research that supports it is secret, and mostly focuses on the active ingredient rather than its hundreds of commercial formulations. Those commercial applications vary in mixtures with other chemicals, and many such combinations remain untested. Its transparency is lacking.

Affecting both participation and transparency, with the exception of the SAICM, the breadth of stakeholder involvement in its governance is narrow, which must weaken both understanding and acceptance of the science involved. As with other chemicals, this can be exacerbated by the silo-like technical expertise about the substance.

There is no single program, process or institution that has global carriage of its regulation. Globally, its sustainability risks are dealt with through voluntarist strategies at state level, together with regulation in industrial countries. While there are relationships between them, leading regulators as in the US, the EU and China take different positions on the substance and its toxicity. While some of this may be due to cultural and economic factors, there is indirect evidence that the rapport between industry and government may be rather too cosy in the US and China. And while the scope of both the WHO and FAO is global, both are focused on human health rather than biodiversity. They also act to limit tighter safety standards in the cause of free trade in food. Despite claims of higher yield and less pesticide use through linking glyphosate with genetically modified crops, evidence is to the contrary (Hakim 2016). Sustainability is better where there is less glyphosate and no genetic modification. This issue is central yet still to be addressed by many regulators. Regulation of technologies in this industry is a patchwork rather than a seamless coherent fabric. The problem of how all these measures can be integrated remains largely unsolved. At this level there is an absence of authority and thus a lack of accountability.

An internationally consistent glyphosate regulation would support better governance. A recent letter to stakeholders from the EPA director of pesticide programs points to a new 'twenty-first century approach' to pesticide testing and assessment (Housenger 2016), based on digital technologies. It is aimed at faster evaluations of more pesticides, using fewer research animals with lower costs. The approach emphasises international cooperation on data sets that relies more on models of established toxicity relationships rather than further direct testing. As such it promises a more coherent international approach to regulation — one that relies more on data analysis for risk assessment. Developing this sort of approach is discussed further at chapter 13.

However, glyphosate governance now faces another challenge. The US\$66 billion takeover of Monsanto by Bayer announced in September 2016 (Roumeliotis & Burger 2016) will be the largest ever by a German company and create a globally dominant chemical and seed conglomerate across agriculture as well as pharmaceuticals. Governance must now grapple with the immense leverage of a global enterprise that stands astride the traditional twin centers of the world chemical industry, in both Germany and the US. Integrity is further threatened.

Yet the October 2016 finding of the international *Monsanto Tribunal* indicates that the law can be used against any unsustainability threat posed by glyphosate as much as it has been to negate adverse findings. Five judges meeting in The Hague using the legal principles of the International Criminal Court, brought down a verdict that Monsanto is guilty of crimes against the planet and humanity due to the effects of glyphosate and genetically modified crops on the ecosystem. While ecocide is yet to be established as an international crime,²²⁰ and Monsanto denounced the tribunal as a “kangaroo court”, the presiding judge said that civil society could help that development in international law (Eradicating Ecocide 2016).

Glyphosate is an example of a market-led approach to governance in which the state is supportive of private development and market access through trade; its support strengthened in this case by strong military links to herbicide and nuclear weapons development. While not all pose the same challenges, its governance issues can apply to other chemical products. These issues include association with the military, commercialisation secrecy, incoherent global regulation, litigation that menaces dissenting research, and the political leverage of big corporate producers. Against the TAPIC governance criteria, transparency, accountability and participation are all sub-optimal due to secrecy and regulatory capture. Integrity is jeopardised by corporate influence. Capacity is sapped by incoherent standards, different institutional focus and lack of stakeholder engagement. These are summarised in figure 33 below:

Figure 33: Glyphosate and other market-led chemical technology governance across TAPIC criteria

Transparency	Accountability	Participation	Integrity	Capacity
Low transparency due to corporate secrecy, patent protection, and relationship with military-industrial complex.	Low accountability due to regulatory capture and capacity of Monsanto to influence science, media and through political connections.	Narrow participation due to exclusive rights of corporations to undertake R&D without wider scrutiny by scientific bodies and civil society.	Low integrity as considerable evidence Monsanto is using its influence to steer scientific, public and political opinion in its favour. Mission clarity divided between global institutions.	Weak capacity of external agents to bring Monsanto to account due to lack of rights and resources. Political capacity to engage stakeholders in policy discussion notably absent. Standards not coherent. Different institutional focus.

Counterweights that favour sustainability include the creation of legal categories that would thwart environmental damage and the use of digital technologies to speed and make more coherent testing through data analysis.

Finally, irrespective of whether it is possible to find Paracelsus’ dosage ‘sweet spot’, glyphosate’s sales success as a weedkiller points to the return of mechanical methods due to the problem of evolved resistance as outlined by Professor Duke above. Robotics look to be one precision alternative that has no harmful environmental effects and thus a sustainability advantage. This is further discussed in chapter 11.

²²⁰ Ecocide is nevertheless a crime in ten national jurisdictions, including Vietnam and the Ukraine.

Chapter 10. Case study: Nuclear-electric power

Human civilisation can flourish for centuries and millennia on energy delivered from a closed uranium or thorium fuel cycle, or from hydrogen-deuterium fusion

— Asafu-Adjaye et al 2015, *An Ecomodernist Manifesto*, p. 10.

Generating electricity involves technologies that form the key platform of modernity, and which are linked to societal affluence (Garrett 2014). They combine significant benefits with big risks. The energy sector generates about two-thirds of global greenhouse gas emissions (IEA 2013, p. 15), sourced mainly from fossil fuels. And about 41 per cent of the energy sector's emissions come from electrical power generation (Ibid, p. 27). While greenhouse gas emissions are by no means the only issue in electricity generation, they are the major cause of climate change. Yet, despite the 2015 Paris climate agreement that limits emissions, there remains a political-technological divide between those who are reluctant to replace fossil-fuelled electricity generation and others who want electricity generation from renewable sources progressed urgently. Both views might rely on Margaret Thatcher's famous dictum: *There is no alternative (TINA)*.

One group argues that only coal-fired plants can provide viable base load power, while the other says that only renewables will prevent the overheating of the biosphere. But contrary to Thatcher's dictum, there is an alternative to these extremes. It is neither fossil-fuelled, nor does it use renewable energy. It provides continuous base-load power and it emits no greenhouse gases during operation. As do fossil-fuelled power plants, it uses turbines spun by steam pressure to turn the electric generators. The key difference is that the heat is supplied not by coal but by nuclear fission.²²¹

Nuclear-electric power is favoured by 'ecomodernists' (Asafu-Adjaye et al 2015), who have been described as the environmental 'centre-left' of the political spectrum (Lynas 2015). They believe that decoupling production from nature using energy-dense technologies will benefit humanity, while at the same time leaving nature more space and less interference. Ecomodernists argue that nuclear power has a demonstrated potential "to reduce human demands on the environment, allowing more room for non-human species" (Asafu-Adjaye et al 2015, p. 18), and that nuclear fission is "the only present-day zero-carbon technology with the demonstrated ability to meet most, if not all, of the energy demands of a modern economy" (Ibid, p. 23). But due to social, economic and institutional "challenges", large scale deployment of the technology is unlikely in the shorter term. New generation fission and fusion technologies are, however, viable in the longer term, according to the '*Ecomodernist Manifesto*' (Ibid).

Many of these "challenges" to nuclear power arise from major accidents that involve contamination of large areas and extensive publicity about nuclear catastrophe. The downside also concerns the proliferation of nuclear weapons material, the high cost of the power plants including construction, operation and decommissioning, the risk of nuclear terrorism and the difficulty of radioactive waste disposal. Further, nuclear plants need long lead times for planning and construction. The inevitability of accidents means that the electricity generated cannot always be relied on as other nuclear plants in the same grid are shut down when catastrophes occur, as happened in Japan after Fukushima in 2011. Given these challenges it is unsurprising that the nuclear industry has struggled to present itself as the answer to future

²²¹ Nuclear fission was discovered in 1938 by Otto Hahn, who was later awarded the Nobel prize in chemistry.

energy needs, despite millions of dollars spent on major public relations efforts (Farsetta 2007).

Nothing exists except atoms and empty space; everything else is opinion - Democritus c.480 BC

Background

While the ancient Greek, Democritus, had postulated the existence of fundamental particles or atoms, it was only at the end of the nineteenth century that radioactive substances were discovered,²²² and in the early 1930s Rutherford at Cambridge found that splitting lithium atoms released vast amounts of energy. The first self-sustaining atomic pile, which created heat in a controlled way, was built in Chicago in 1941. The first (experimental) reactor producing electricity was built in 1951, also in the US (USDoE 1994, p. 8), and the first commercial nuclear power plant was opened at Windscale in the UK in 1956. In the US, the 1957 Price-Anderson Act²²³ limited the liability of firms for nuclear accidents and helped them secure capital with federal loan guarantees, such that more than 100 nuclear plants were built by the early 1970s (Jenkins et al 2010, p. 26). Construction of nuclear electric plants elsewhere continued in a stuttering way until by 2016 there were 449 plants in operation in the world, 60 reactors under construction, two in long-term shutdown and over thirty permanently closed (IAEA PRIS 2016). All use uranium as a fuel. Apart from the four major incidents that received extensive publicity,²²⁴ Windscale (UK 1957), Three Mile Island (USA 1979), Chernobyl (Ukraine 1986), and Fukushima (Japan 2011), there were about 100 “significant accidents”²²⁵ at nuclear power plants between 1952 and 2009, involving more than US\$20 billion in damages (Sovacool 2010).

Connections

There are people connections between the regulation of pesticides and the generation of nuclear power. In the US, part of the nuclear-electric public relations effort has involved setting up industry funded pro-nuclear front groups. People with ‘green’ associations are highly valued recruits. As a result, former EPA chiefs, Christine Whitman and Carol Browner have taken prominent positions with pro-nuclear organisations since they left the Agency. Whitman is now co-chair of the ‘Clean and Safe Energy Coalition’ (CSEnergy), which is funded by the industry *Nuclear Energy Institute* (Farsetta 2007). Browner is a leader of the advocacy group ‘*Nuclear Matters*’. Another former EPA chief, William Reilly, is also a prominent campaigner (Nuclear Matters 2014; Manjunatha 2016). In these cases, two were appointed to the EPA by Republican presidents, one by a Democrat,²²⁶ so it is a bipartisan phenomenon that evidences close ties between government regulators and the nuclear power industry in the US.

Also, both herbicides and nuclear power grew from military applications fostered by government, especially in the US and UK. Nuclear military applications were also developed in France from 1945 and its first nuclear electric plant opened in 1962. In 2016 France had the

²²² By Henri Becquerel (France) in 1896. The becquerel (Bq) is now the SI unit of radioactivity, defined as the number of radioactive transformations per second. When used to measure activity in soil, food, and water, it is typically expressed as Bq/kg or Bq/m³.

²²³ The *Price-Anderson Nuclear Industries Indemnity Act* has been amended several times and applies at least until 2023.

²²⁴ The Kyshtym (Russia 1957) disaster was also a major incident but it was not a nuclear-electric plant and there was little publicity due to the Cold War.

²²⁵ Incidents resulting in loss of human life or more than US\$50,000 of damage, based on US mandatory reporting criteria.

²²⁶ Whitman was appointed by Bush the elder, Reilly by Bush the younger and Browner by Clinton.

highest proportion of electricity generated from nuclear power of any country – around 75 per cent. Due to the 1973 oil crisis when much of the country's electricity was generated from imported oil, the 'Messner Plan' was implemented aiming to produce all France's electricity from nuclear power on the popular rationale of: "no oil, no gas, no coal, no choice" (Palfreman 1997). Despite major accidents elsewhere, nuclear power remains popular in France for several reasons: a relatively good safety record, lack of alternatives, a national regard for elite technocrats, strong government ownership, and a low retail price of electricity (Ibid). These factors have also made nuclear-electric power an important export industry, as discussed in chapter 8 above.

Dosage is yet another nexus. Both the nuclear and pesticide industries are critically concerned with the issue of 'safe dose' for risk estimates. The nuclear risk profile has relatively low probability of happening combined with high impact should an accident occur, while pesticide contamination may be more likely but with lower impact. A common assumption of nuclear radiation risk is that no dosage is safe and there is a linear relationship between exposure and harm (IAEA 2011). Exposure at significantly more than the level of natural background radiation is therefore cautionary. Figure 34 below lists different radiation exposures, measured in millisieverts (mSv),²²⁷ that relate to human biological impact (Chandler 2011). It shows that the recommended limit for workers exposed to nuclear radiation is 20 millisieverts per year against typical natural radiation of 2 millisieverts per year – a tenfold difference.

Figure 34. Radiation exposure comparisons

2 mSv/year	Typical background radiation experienced by everyone
1.5 to 2.0 mSv/year	Average extra dose to Australian uranium miners, and medical.
2.4 mSv/year	Average extra dose to US nuclear industry employees.
up to 5 mSv/year	Typical incremental dose for aircrew in middle latitudes.
9 mSv/year	Exposure by airline crew flying the New York - Tokyo polar route.
10 mSv/year	Maximum dose to Australian uranium miners.
20 mSv/year	Current average limit for nuclear industry employees and uranium miners.
50 mSv/year	Former routine limit for nuclear industry employees.
100 mSv/year	Lowest level at which increase in cancer is clearly evident.
250 mSv	Limit for emergency workers at Fukushima Japan, 2011.
350 mSv/lifetime	Criterion for relocating people after Chernobyl accident.
500 mSv	Symptoms of radiation poisoning become evident.
1,000 mSv/cumulative ²²⁸	Probably cause fatal cancer in five of every 100 people exposed to it
1,000 mSv/single dose	Radiation sickness (nausea and decreased white blood cell count).
5,000 mSv/single dose	Death for c. half those exposed within a month (similar to Hiroshima 1945).
10,000 mSv/single dose	Fatal within a few weeks.

Sources: World Nuclear Association, 2004; Chandler 2011.

²²⁷ This is essentially a measure of the amount of potential damage to the body from a given amount of radiation.

²²⁸ The UNSCEAR (1994, p. 3) report to the General Assembly establishes 5 per cent fatal cancer rate for each Sievert (1000 mSv) of exposure.

The increased dosage limit (250mSv) for emergency workers at Fukushima in 2011 in the table above is an example of the regulatory ‘bracket creep’ that has also occurred with glyphosate tolerances. Although it is a total rather than a rate of dosage, it suggests that regulations were adjusted to accommodate hazards, instead of measures developed to avert them. This compares with the following dosage limits (above background levels) according to three international organisations (figure 35), which are consistent, and considerably lower than dosages experienced at both Chernobyl and Fukushima:

Figure 35. Radiation dosage limits above background levels by international organisation

2016	IAEA	ICRP ²²⁹	EU
General public	≤1 mSv/year	≤1 mSv/year	≤1 mSv/year
Licensed workers over 18 yrs	≤ 20 mSv/year	≤20 mSv/year	≤ 100 mSv over 5 consecutive years
Workers 16-18 years	< 6 mSv/year	< 6 mSv/year	< 6 mSv/year

Source: IAEA 2011

Especially given that young people are particularly susceptible to radiation, the employment of 16 year olds at nuclear plants is a probable breach of ILO Conventions on child labour including C138, article 3.1: *“The minimum age for admission to any type of employment or work which by its nature or the circumstances in which it is carried out is likely to jeopardise the health, safety or morals of young persons shall not be less than 18 years”* and C182, article 3d, which prohibits *“work which, by its nature or the circumstances in which it is carried out, is likely to harm the health, safety or morals of children”*.

Further, these kinds of tables can mislead. It is not immediately obvious that the rate of exposure is as important as the total amount. Further, there is a difference between the external exposures reflected in most of these figures and the internal exposures that result from longer term inhalation, absorption and ingestion of radioactive substances due to contamination by fallout. In contaminated areas those high in the food chain are at greater risk because contamination is accumulated through diet. These internal exposures produce cumulative genetic damage leading to cancers – later and separate from the effects of the external exposures described in most of the dosage limits above (Caldicott 2011). Along this fault line, a typical pro-nuclear argument is that there were no deaths directly due to radiation exposure at Fukushima. The contrary view is that there will be many indirect deaths due to fallout and ingestion of contaminated food over an area shaped by the prevailing winds originating from the disaster site. There will also be many cancers, especially of the thyroid, that may not register as fatalities (Tsuda et al 2016)²³⁰ and to which children are particularly susceptible (WHO 2016).

Regulation

Regulations about relatively safe exposure levels can also be confusing and the issue is contested. For example, current standards are based on the conservative assumption that risk is directly proportional to the dose, called the 'linear no-threshold (LNT) hypothesis', although other bases are proposed. These other (higher) bases, include the ‘as low as reasonably achievable’ (ALARA),²³¹ the ‘as high as naturally existent’ (AHANE), and ‘as high as relatively safe’ (AHARS) – which is about 1000mSv per year. All are mentioned as possible approaches to

²²⁹ ICRP: International Commission on Radiological Protection, an international NGO.

²³⁰ Thyroid cancers are due to the ingestion and concentration of radioactive Iodine. Even if successfully operated upon they often lead to significantly reduced quality of life.

²³¹ Taking social and economic factors into account.

the issue of limits by the industry-based World Nuclear Association,²³² which argues that there is probably a threshold below which there is no risk and that exposure to radiation is much less harmful than is usually assumed (WNA 2016).

Like Gaul the area of nuclear technology is divided into three parts: a zone of non-patentability, a zone of government patents, and a zone of private patent rights

– Riesenfeld 1958, p. 51).

Only some nuclear technologies may be patented. The 1954 *Atomic Energy Act* is the seminal US legislation regulating nuclear energy, which has been supplemented several times due to treaty obligations, but remains largely intact. It followed an earlier 1946 law that was primarily to ensure government control over its military applications. By contrast, a central purpose of the 1954 Act is “to make available to cooperating nations the benefits of peaceful applications of atomic energy as widely as expanding technology and considerations of the common defence and security will permit” (s.3e). Following considerable political pressure and much amendment regarding patent rights (Riesenfeld 1956), the Act excludes patent rights for inventions that can be used solely in atomic weapons (USPTO 2016), but provides for patents in non-military applications such as electricity generation. There is also an ‘intermediate zone’ whereby the patent office must report nuclear inventions (to the Department of Energy) and the government may subsume patent rights with appropriate compensation,²³³ irrespective of their military or non-military application. As such it is an attempt to balance the need for security in military matters against commercial incentives for innovation.

The Act also establishes the *Atomic Energy Commission*, and asserts a licensing requirement for all activities concerning nuclear material (s.101). However it mentions nuclear safety only fleetingly – but twice in its 276 pages – in relation to cooperation with the states on a federal radiation council (s. 274) and in relation to standards for uranium mill tailings (s. 275).

As to international regulators, the independent International Commission on Radiological Protection (ICRP)²³⁴ was formed in 1928 to provide scientific advice on the effects of all forms of radiation, well before nuclear power plants were conceived. This NGO has its secretariat in Ottawa, Canada, and is accredited with several UN agencies including the WHO, FAO and the ILO, as well as the International Atomic Energy Agency (IAEA). Its recommendations on policy and standards are widely followed by national health authorities.

The IAEA is a semi-independent UN body with statutory responsibilities for nuclear safety that develops non-binding standards²³⁵ based on ICRP recommendations. Following Eisenhower’s 1953 “*Atoms for Peace*” speech to the UN General Assembly and the expediting 1954 US *Atomic Energy Act*, the IAEA was set up in Vienna in 1957 to “to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity through the world” [Article II] as well as, in consultation with other agencies, “to establish or adopt...standards of safety for protection of health and minimisation of danger to life and property” [Article III A.6]. The IAEA

²³² The World Nuclear Association represents industry from all segments of the nuclear fuel cycle including uranium mining, plant construction, transport, plant operation and nuclear waste disposal.

²³³ Compensation may be additional to patent rights and is determined by the AEC patent compensation board (Boskey 1956, p. 119)

²³⁴ The Swede, Rolf Sievert, was the first president of the Association and is commemorated in the unit of ionising radiation that bears his name.

²³⁵ Although any state that accepts help from the IAEA must also accept its safety standards.

is also responsible for measures to contain the spread of nuclear weapons [Article III A.5], a task at which it has not been entirely successful.²³⁶

The UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), set up in 1955, is an authoritative source of information specifically on the effects of the ionising radiation that results from nuclear materials (as distinct from the wider radiation concerns of the ICRP), based on assessments of the scientific literature. It provides appraisals to both the ICRP and the IAEA. National governments set radiation protection standards generally in line with ICRP recommendations, keeping exposure as low as reasonably achievable (ALARA).

Also based on ICRP recommendations, the European Commission (EC) develops binding directives that its member states must transpose into national law. The OECD *Nuclear Energy Agency* (NEA) investigates emerging issues in radiological protection when invited by member countries. It also tests draft recommendations of the ICRP before they are finalised (Lazo 2009).

It is in this global regulation of nuclear power that there is an intriguing asymmetry involving the IAEA and the WHO. The IAEA was primarily created to *promote* non-military nuclear energy. Its *regulation* of that energy, however, is a secondary function that involves consultation with other agencies and member states. Yet that consultation works both ways and the agency's overriding promotional objective tends to overshadow its relationships. For example, before the IAEA was established, the WHO issued strong public warnings about the health risks of the nuclear industry, as in 1956 when it said "the health of future generations is threatened by increasing development of the atomic industry and sources of radiation". However, in 1959, two years after the IAEA was established, the WHO became muted due to a formal pact with the IAEA that required them to consult on relevant activities "with a view to adjusting the matter by mutual agreement" (clause 12.40, cited in Caldicott 2011). Current WHO statements consist of factual information on the health effects of radiation rather than dire warnings of nuclear threats to posterity (WHO 2016).

This clubby multi-agency arrangement of dispersed responsibility began to appear lax when the size of the 1986 Chernobyl disaster became apparent. In response, the IAEA facilitated a binding *Convention on Nuclear Safety* (CNS), which all countries with nuclear power plants (except Iran) agreed to – albeit a full eight years after the disaster, in 1994. The CNS commits countries (and the EU) to specific nuclear safety measures that include licensing (article 7) principles of oversight (article 8) and systematic safety assessment (article 14), although not to any technical benchmarks, which remain voluntary. Every three years under the Convention there is a peer-review system of country reports on the management of nuclear safety (article 5) aimed at identifying good practice as well as flaws in national supervision.

However the Convention itself proved inadequate when Japan reported in 2010 that it was in compliance, whereas in fact it was not – especially concerning regulatory independence (article 8.2) and safe siting of nuclear power plants (article 17). The Fukushima disaster occurred the following year, exposing "certain weaknesses in Japan's regulatory framework" (Dahl 2015). According to the IAEA Director General, Yukiya Amano – himself Japanese – "responsibilities were divided among a number of bodies and it was not always clear where authority lay". Underlying this,

²³⁶ Given that there are nine nuclear weapons states possessing a total of more than 15,000 nuclear warheads, according to the Arms Control Association (2016).

a major factor that contributed to the emergency was a widespread assumption in Japan that its nuclear power plants were so safe that an accident of such a magnitude was simply unthinkable. This assumption was accepted by nuclear plant operators and was not challenged by regulators or by the government (Ibid).

Russia, Switzerland and the IAEA itself then proposed that IAEA safety standards and peer reviews be compulsory. The proposition failed. Switzerland and the EU then further proposed that the CNS include compulsory safety targets for all reactors, but this was again opposed by countries such as the US, India and China that feared extra costs and domestic interference. It is probable that the US especially was wary of cost implications since US reactors vie in intensely competitive electricity markets, whereas European reactors tend to operate with more government control, in more regulated electricity monopolies where costs are less critical (Hibbs 2016).

Beyond these inadequate governance arrangements, in response to Chernobyl the industry itself formed a non-profit association that focused uniquely on safety rather than the promotion of nuclear electric power. The World Association of Nuclear Operators (WANO) was formed in 1989 and has headquarters in London, UK. It represents almost all operators of individual nuclear power plants, undertakes external peer reviews and provides operational and technical support and professional development. Immediately after Fukushima WANO convened a commission to report on needed changes to the organisation. The five recommendations were:

1. To extend the scope of WANO to include design and accident management
2. To set up an event response strategy
3. To increase WANO's credibility through stronger internal control
4. To increase WANO's transparency by making WANO regular reports accessible to the public
5. To increase internal consistency between its four regional centres (Chudakov 2014).

In effect, these measures accept that nuclear power plant accidents are inevitable. Beyond maximising safety through prevention, they recognise that there must be an effective response when accidents occur. In respect of the transparency recommendation #4, however, as of mid 2017 very few reports were available to the public on the WANO website, apart from some brochures on global performance indicators and a list of safety measures. Detailed reports appear to be restricted to members.

Human mortality

Despite the setbacks due to nuclear accidents, pro-nuclear public relations agents²³⁷ and academic research have both tackled the nuclear power safety issue directly. Articles comparing nuclear mortality with other means of electricity generation are becoming more common. For example, the following table (figure 36) was published in the influential US *Forbes* business magazine in an article arguing that nuclear is the least harmful form of electricity generation to humans. The piece has since prompted hundreds of comments over a period of four years.

²³⁷ According to the European energy consultant, Mycle Schneider, "the international nuclear lobby has pursued a ten-year long massive propaganda strategy aimed at convincing decision-makers that atomic technology has a bright future as a low-carbon option" (Schneider 2011).

Figure 36. Human mortality rate per energy source

Energy source	Deaths per trillion kWh	Per cent energy or electricity
Coal – global	100,000	50% of global electricity
Coal – China	170,000	75% of China’s electricity
Coal – US	10,000	44% of US electricity
Oil	36,000	36% of energy, 8% of electricity
Natural Gas	4,000	20% of global electricity
Biofuel/Biomass	24,000	21% of global energy
Solar (rooftop)	440	<1% of global electricity
Wind	150	~1% of global electricity
Hydro – global	1,400	15% of global electricity
Nuclear – global	90	17% of global electricity with Chernobyl and Fukushima
Hydro – US	0.01	7% of U.S. electricity
Nuclear – US	0.01	19% of U.S. electricity

Source: Conca 2012

While the table appears persuasive, alas the figures do not add up: all the ‘global’ percentages for each electricity source total just under 104 per cent. Assuming that the figure for oil generated electricity is also global and that biomass accounts for some electricity generation, total global electricity is more than 112 per cent. Moreover, the figures are not sourced, nor is the year given, which cast further doubt their validity.²³⁸

By contrast, the International Energy Agency (IEA) provides the following figures for 2014 that do add to 100 per cent and are probably more reliable (IEA 2016, p.3):

In 2014, 66.7% of world electricity production was from fossil fuel generating plants. Hydro electric plants provided 16.4%, nuclear plants 10.6%, biofuels and waste 2.1%, and geothermal, solar, wind and other sources made up the remaining 4.2%.

These are considerably different from the figures in *Forbes*, especially for nuclear at 10.6 per cent compared with Conca’s 17 per cent, and fossil fuels at 66.7 per cent compared with Conca’s 78 per cent. Such divergence in basic figures suggests that, as with glyphosate, nuclear-electric technology is a crucible of controversy. In fact, the conflict over nuclear power has been described as having “an intensity unprecedented in the history of technological controversies” (Kitschelt 1986, p. 57), visible in mass demonstrations in many countries, especially those following the four major and most public nuclear accidents.

A more rigorous study, still favourable to nuclear power, came from NASA’s Goddard centre. According to the study, nuclear power has saved millions of lives:

nuclear power prevented an average of over 1.8 million net deaths worldwide between 1971-2009 [over 47,000 per year] ...This amounts to at least hundreds and more likely thousands of times more deaths than it caused. An average of 76,000 deaths per year were avoided annually between 2000-2009...with a range of 19,000-300,000 per year (Kharecha & Hansen 2013, para 4).

²³⁸ I put this to Dr Conca in September 2016 on the article’s comments site. His immediate published response ignored the points made: “Sorry, that was four years ago and those numbers have changed dramatically since. Will go back and fix when I get a chance”.

Dr Kharecha confirms that the higher rate of avoided deaths in later periods is attributed simply because there were more nuclear plants then operating.²³⁹ But accepting that these estimates are valid, the logic is constrained. These numbers are based on estimated deaths mainly from the inhalation of particulates from fossil-fuelled plants. The scenarios in the article assume that “nuclear energy is cancelled and replaced entirely by energy from either coal or natural gas” (Ibid). Yet this does not have to be the case. Renewable and distributed sources can also substitute for nuclear; they are much more quickly constructed than nuclear plants and have more public acceptance. In fact, the *Lancet* article on which Kharecha & Hansen rely for their estimates, indicates that a decision to replace current nuclear power plants:

would be welcome in health terms if the nuclear plants were replaced by capacity in renewable production additional to the level of renewable production that would otherwise occur (Markandya & Wilkinson 2007, p. 988).

Also, the wide range of ‘deaths avoided’ in the study — between 19,000 and 300,000 per year — indicates uncertainty about the true figure. That figure must be high as there are seven million early deaths each year from all sources of air pollution (WHO 2014b), many of which must be from coal and gas-fired electricity, especially in China and India.²⁴⁰ But on the nuclear ‘deaths caused’ side of the ledger, estimates also vary widely. For example, the Belarussian scientist Malko’s 2006 study on Chernobyl estimated more than 90,000 excess cancer deaths, and his later study showed more than 115,000. This contrasts with a WHO prediction of 9,000 additional deaths due to Chernobyl (Dawe et al 2016, p. 25). Peplow (2011) reporting in *Nature* says study estimates “range from a few thousand to hundreds of thousands” of deaths due to the disaster. Further, the issue of contamination continues over many decades: Cesium 137, which forms much of the radioactive fallout from both Chernobyl and Fukushima has a half-life of 30 years (Schneider 2011).

In China, the Fukushima effect was more economic than physical, probably because the prevailing winds are westerly, blowing fallout across the Pacific rather than towards the Asian continent. Land prices within 40 kilometres of a nuclear power plant in China fell by about 18 per cent a month after the disaster, eventually returning to normal only years afterwards (Zhu et al 2016). China’s State Council did suspend nuclear plant development (Schneider 2011), but construction has since resumed.

Comparisons

Apart from these accident risks, the emissions and costs of nuclear power can be compared with other sources of electricity, key factors in any political consideration. Figure 37 below shows emissions and costs from existing and possible future sources, based on IPCC data. Calculations are for the life cycle of each source, including materials, construction, and ultimate remediation.²⁴¹ Nuclear emissions and costs include the mining, processing and transport of uranium, construction of reactors and insurance costs against the risks of disaster. Hydro-electric generation includes the emissions and running costs of the construction machinery used, as well as for the dams and turbines. Social and direct environmental costs such as the loss of habitat due to dams and coal mines are not included. Notably, the data²⁴² assume there is a distribution grid, which skews cost advantage away

²³⁹ Personal email of 2 September 2016.

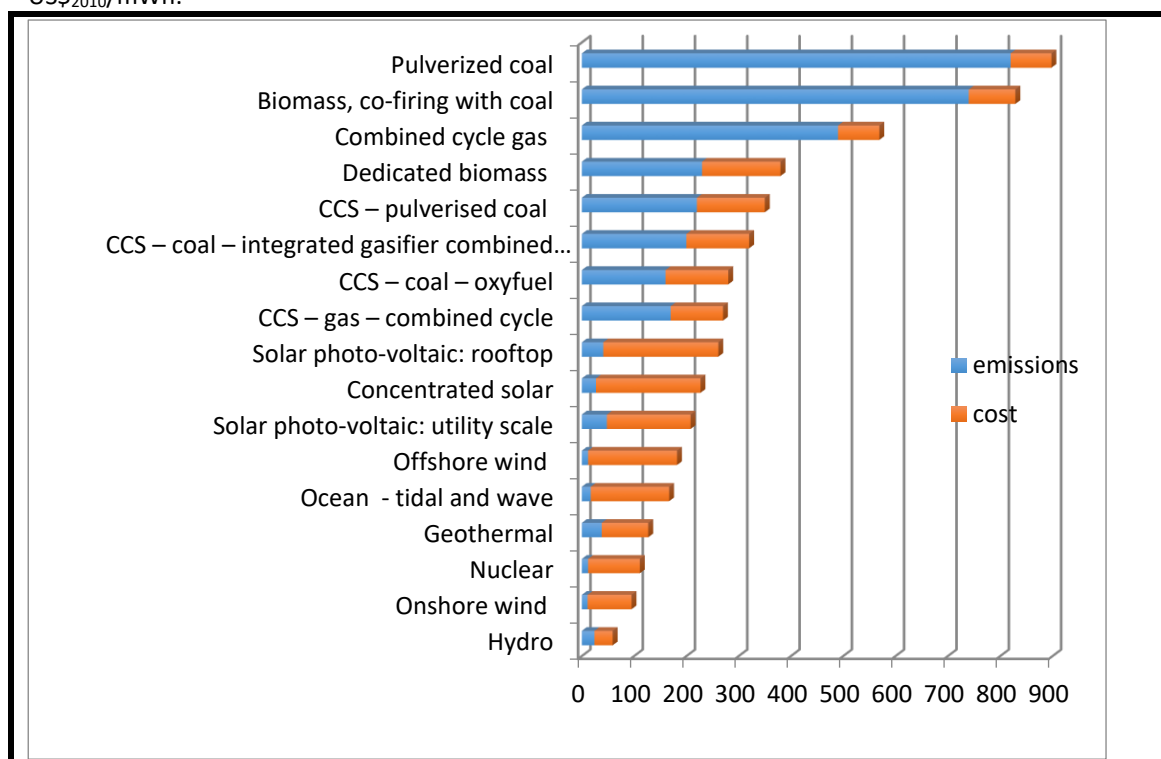
²⁴⁰ As well as to other sources such as fuel stoves, steel production and transport, for example.

²⁴¹ The only significant remediation cost is for nuclear; others are assumed to be negligible.

²⁴² The data are the “levelised cost of electricity” assuming 10 per cent “weighted average capital cost” (WACC) and high “full load hours” (FLH) of production. Figures for 5 per cent WACC and low FLH are

from rooftop solar in developing countries, where nuclear and all other forms of generation would require a grid to be built.

Figure 37. Total greenhouse gas emissions plus total cost of electricity by source. Zero carbon price. CCS: carbon capture and storage (not yet commercial.²⁴³) Emissions: kgCO₂eq/mWh. Cost: US\$₂₀₁₀/mWh.



Source: Based on data in IPCC 2014c, pp. 1333-1335.

If cost were the only consideration, coal, biomass-coal, gas, geothermal, onshore wind and hydro are all more viable than nuclear. However, when emissions and cost are combined as in this comparison, nuclear is the third most viable form of generation, after hydro and onshore wind. When carbon pricing is included, nuclear remains the third most viable against these two combined criteria as the advantage of all non-fossil-fuelled sources is considerably increased.

The data show that the range of costs (from 35 to 220 USD/mWh) is much narrower than the range of emissions (from 11 to 820 kgCO₂/mWh). Whilst it has been argued to the contrary, the cost of fossil fuels is unlikely to rise much in the medium term. Supplies are not yet at the point of exhaustion due to new extraction methods and there are still considerable reserves (Helm 2013). Yet largely due to economies of scale in manufacturing, the cost of solar photo-voltaic has been continually falling in real terms. Increasingly, renewable sources (that use free fuel) are among the cheapest and becoming cheaper, rivalling the cost-emissions advantage of nuclear. It is also a considerable disadvantage that nuclear has very high upfront costs as well as long lead times (Findlay 2010).

However, these two categories are necessary but not sufficient to determine a viable energy policy and the place of nuclear within it. Not only is energy desirably clean and cheap, it is also

also available, but not used here for the sake of simplicity and because some data appear to be mislabelled in the IPCC report.

²⁴³ Although according to Service (2017) it is close to being so in Texas, US.

an advantage that it is continuous, whether provided directly or as a result of storage, and desirably inexhaustible. There are also locational factors: it is obviously not possible to locate offshore wind farms in landlocked countries, for example. Nor is hydro power feasible without rivers. Coal and nuclear power stations have locational problems associated with pollution and safety, and nuclear carries additional risks of major catastrophe, nuclear proliferation and waste disposal.

The prolific energy policy analyst, Benjamin Sovacool (2010) judges nuclear and renewable technologies against six criteria: cost, fuel availability, land degradation, water use, safety and security, as well as 'climate change' – the equivalent of greenhouse gas 'emissions'. Writing before Fukushima, Sovacool finds that for nuclear, the costs of construction, fuel, and decommissioning will probably increase. Further, nuclear reactors are prone to accidents and failures, imminent shortages of quality uranium ore, the degradation of cooling water and the issue of nuclear waste storage. Writing after Fukushima, Tickell (2012) is even more critical. He points out that in a world that relied on nuclear energy:

Serious accidents, such as those at Windscale,²⁴⁴ Three Mile Island, Chernobyl and Fukushima – the last of which came very close to making Tokyo uninhabitable for decades to come – would become commonplace events.

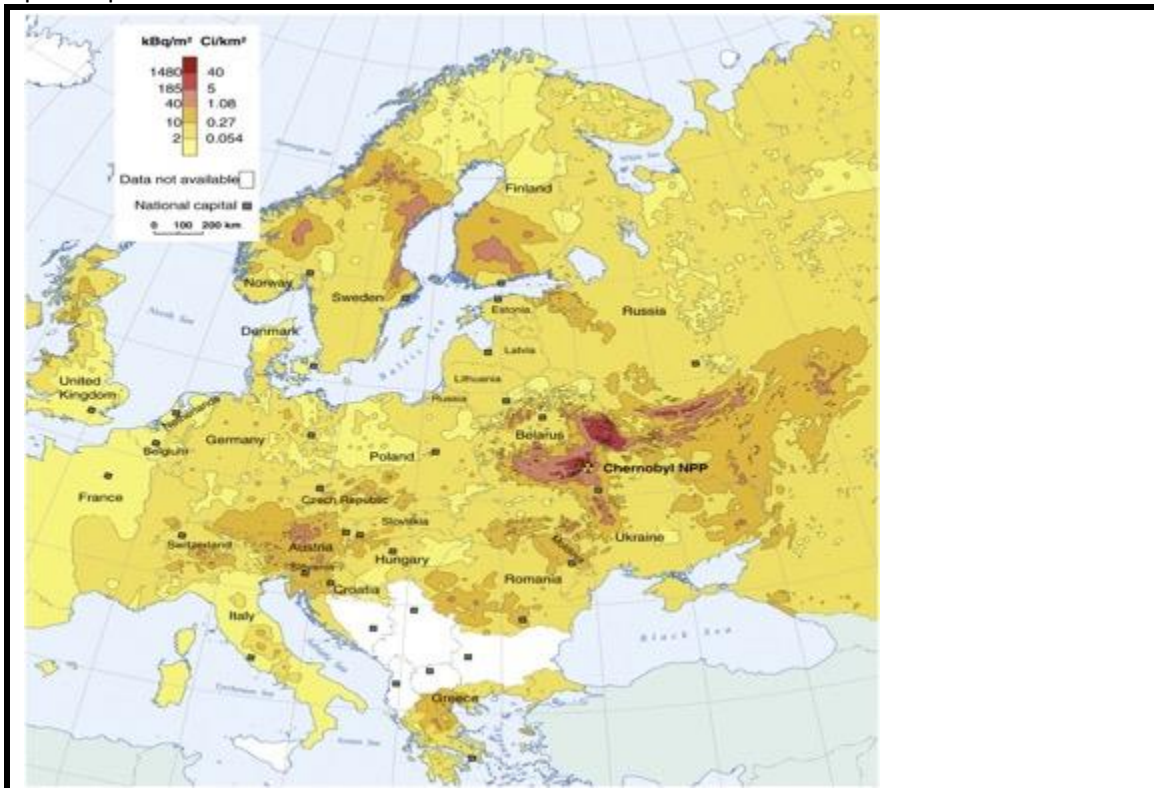
Disasters

Another leading energy academic is cited as predicting the total demise of nuclear electricity if there is one more major disaster within the next five or ten years (Beale 2016). Yet there appears to be a disconnect between this reality and energy policy research, which tends to be technical, narrow and masculine. Sovacool's (2014) meta study of 4,444 full-length articles published between 1999 and 2013 showed that the social dimensions of energy use were undervalued; studies were biased towards science, engineering and economics over other disciplines; there was little interdisciplinary collaboration; and women and minority group authors were under-represented. Layperson viewpoints were ignored and quantitative research dominated over qualitative (Ibid, p. 530).

These findings resonate particularly for nuclear electricity, because the societal and ecological impacts of disaster are its greatest challenge. The sheer scale of disaster most haunts human imaginings over both space and time. For example, 100,000 people were evacuated in 1986 from the Chernobyl exclusion zone, a 2,800 square kilometre area within a 30 kilometre radius from the accident site. Later a further 200,000 people were evacuated from the three countries most contaminated by radioactive fallout – Belarus, Russia and the Ukraine. Some five million people continued to live in these areas that are still contaminated by the accident (IAEA 2006 p. v). Release of radioactive particles into the atmosphere from the accident continued for ten days, so that different wind directions produced three main plumes over the period. As a result, many countries such as Austria, Germany, Switzerland and Greece were also affected by fallout, as shown in figure 38 below. In Scandinavia, the native Saami people were unable to eat contaminated reindeer meat (Ibid p. 4). In large areas closer to the site children drank contaminated milk unaware of the risk of thyroid cancer.

²⁴⁴ A three-day fire in 1957 that released radioactive contamination.

Figure 38. Europe and USSR: contamination from Chernobyl. Surface density of cesium 137. kBq/m²: kiloBecquerels per square metre; Ci/km²: Curies per square kilometre. NPP: nuclear power plant.



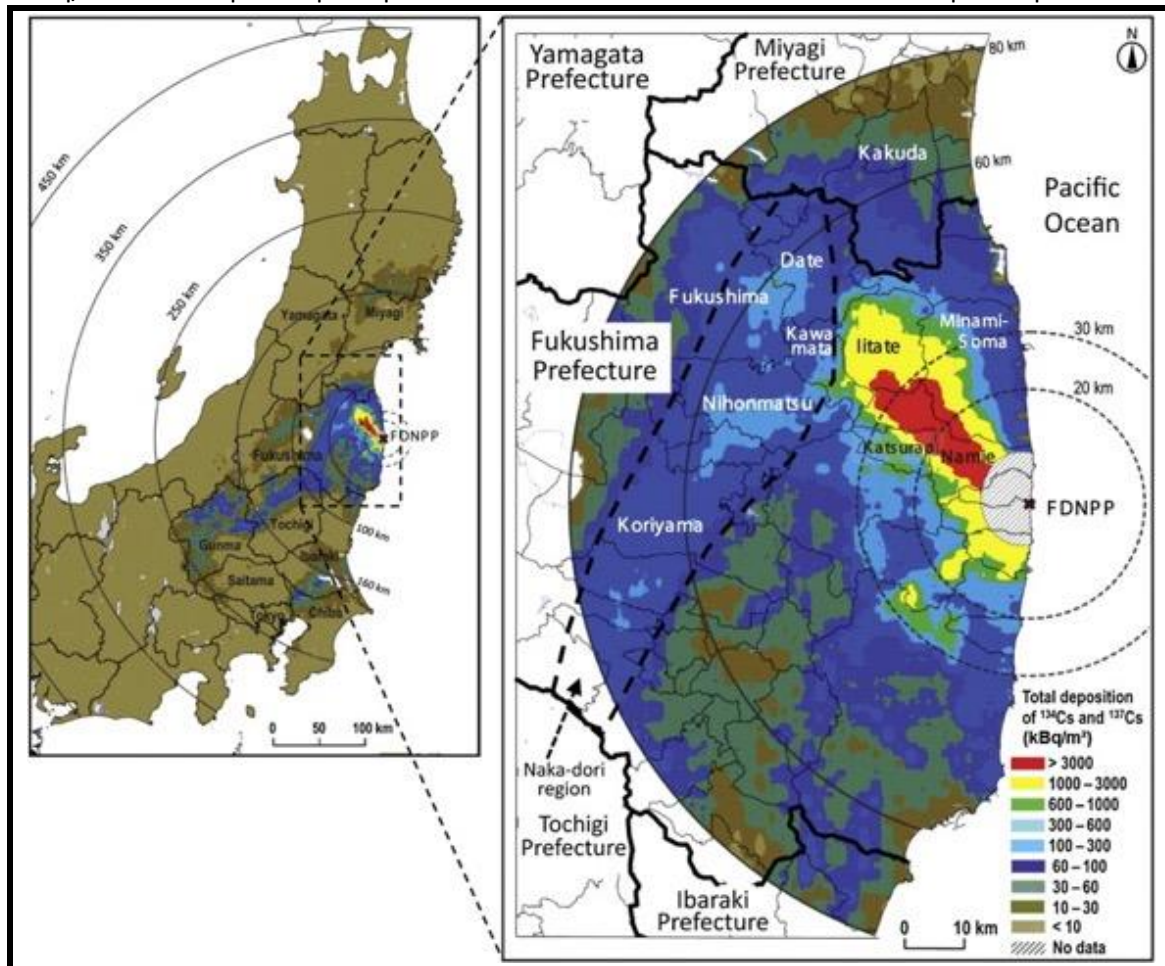
Source: Steinhauser et al. 2014

While some fallout was relatively short-lived with half lives of only a matter of days, cesium 137 continues to cause disquiet as it formed the bulk of the fallout due to its 30-year half-life. In these contaminated areas, the highest concentrations of cesium 137 are found in woodland organisms because it is recycled in forest ecosystems. The level is still above intervention limits in many countries and “can be expected to continue for several decades to come” (IAEA 2006, p. 3). For example, Norway's reindeer remain radioactive as they feed on contaminated lichen and mushrooms. Despite another example of bracket creep in which the Norwegian food contamination limit is five times the EU limit,²⁴⁵ as recently as 2014 reindeer were found still too radioactive to slaughter for food (Taylor 2016).

The Fukushima accident led to more than 150,000 people evacuated from towns within 30 kilometres of the plant, an area of about 1100 square kilometres, as shown in figure 38 below. It had “a massive impact on the atmospheric and natural environment, the economic and political situation, and human psychology and health” (Barletta et al 2016). Most evacuees remained in temporary accommodation five years after the explosion. Contamination was much less than Chernobyl, however, as can be seen by comparing figures 38 and 39.

²⁴⁵ EU limit is 600 becquerels per kilogram.

Figure 39. Honshu: contamination from Fukushima. Surface density of cesium 134 and 137. kBq/m²: kiloBecquerels per square metre. FDNPP: Fukushima Daiichi nuclear power plant.



Source: Steinhauser, Brandl & Johnson 2014

This was because much of the Fukushima fallout was swept over the ocean and the volume of radioactive particles released was only about a tenth of the Chernobyl explosion (Ibid). Health effects were further reduced because Fukushima happened on 11 March, before the main agricultural season, and fallout tended to avoid agricultural areas. The Chernobyl accident was on 26 April, when the growing season had begun and fallout settled directly on crops and pasture (Steinhauser, Brandl & Johnson 2014, s.7).

Different regulators made divergent recommendations and efforts concerning their own citizens living in or visiting Japan at the time of the disaster. The US Nuclear Regulatory Commission, for example, advised Americans in the region to evacuate to 80 kilometres from the site (Eisler 2012, p.31). So did Sweden. Others, such as South Korea and Germany facilitated evacuation from Tokyo and other cities, as did many other countries (*Philippine Daily Inquirer* 2011).²⁴⁶ Although the logistics would have been prodigious, the Japanese government also considered such a measure for its own people in Tokyo.

Estimated deaths from Fukushima, like Chernobyl, are inexact. But despite greater population density in Japan, far fewer will die due to the lower fallout. One study that used extensive modelling suggests radiation exposure will result in an extra 130 (range: 15–1300) deaths from cancer and 180 (range: 24–2500) cancer-related morbidities (Ten Hoeve & Jacobson 2012, p.

²⁴⁶ 'Foreigners Stream out of Tokyo', 18 March.

8743). Others estimate around 1000 fatal cancers due to the disaster, which is within the range of the 2012 figures (Beyea et al. 2013; von Hippel 2011). This last figure is also reasonably consistent with Malko's estimates for Chernobyl (90,000-115,000 deaths) that was ten times more severe and lasted much longer. Deaths from causes other than radiation due to the Fukushima disaster could be up to 600 (Ibid). Non-fatal cancers are ignored in these estimates. Even when in future decades the human impact can be better ascertained, it is still likely that different methods and researchers will produce different results.

Waste

Yet while the impact of nuclear disasters may haunt us over decades, the time periods involved in nuclear waste disposal are very much greater – on a such a scale that the intervals of all other terrestrial technologies are indiscernible:

Since the only way radioactive waste finally becomes harmless is through decay, which for high-level wastes can take hundreds of thousands of years, the wastes must be stored and finally disposed of in a way that provides adequate protection of the public for a very long time²⁴⁷ (USNRC 2016).

The regulation of nuclear waste storage is again nationally determined, hopefully consistent with IAEA guidelines. But one overwhelming problem is that as yet there is no permanent developed repository for high-level waste – the kind produced by nuclear power plants. At present high-level waste is contained on site, usually within the boundaries of nuclear power plants in temporary containers. It is universally agreed that 'deep geological burial' is the long-term solution to the problem, yet not one such shaft has been opened since the first nuclear power plant began operating in 1956 (Findlay 2010, p. 18), although Finland is preparing a such a facility due for commercial use in 2020 (ABC 2016).

Understandably there is extreme political sensitivity about the establishment of a nuclear waste dump. Japan once attempted to encourage its more than 3,000 municipalities to volunteer a site in 2002. Several years later not one willing candidate had emerged (*The Japan Times*, 2014).²⁴⁸ Regional repository schemes have been proposed, but do not overcome the issue of local reluctance. Perhaps only comprehensive national consultations "aimed at reaching consensus on a long-term nuclear waste management strategy" as in Sweden and Canada may have any glimmer of success (Findlay 2010, p. 18), although a proposed referendum in the state of South Australia on the issue appears doomed (Wills 2016). Politically it has taken a long time to develop facilities for waste disposal, although nowhere near as long as will be needed for the waste to become harmless.

Even twenty years after the event,

a comprehensive program for radioactive waste management has not yet been established for further clean up of contaminated areas or temporary radioactive waste facilities at the Chernobyl nuclear power plant and within the CEZ [Chernobyl exclusion zone] (IAEA 2006, p. 159).

It does seem that the effective international regulation of the nuclear power industry is just too much of a challenge for current human institutions, many of which have overlapping and unenforceable responsibilities, as much as its sustainability founders on the twin issues of

²⁴⁷ The half-life of depleted uranium (U-238) is 4.5 billion years, about the age of the Earth. The half-life of the plutonium in Chernobyl's reactor is 240,000 years.

²⁴⁸ Editorial, 'Japan's nuclear waste problem', *The Japan Times*, 21 January 2014.

disaster and waste. Even if, despite the doubts of energy analysts (e.g. Brutoco 2014, Johnstone et al 2016), newer safer nuclear technologies are developed over the medium term as ecomodernists hope, it may be too late for the future of the industry.

This is primarily a state-led example of technology governance, due to its implications for national security and evidenced by the heavy involvement of the five veto powers – the US, UK, Russia, France and China governments in its development. Despite its major risks governance does not seem effective. On the TAPIC measures, the transparency promise of WANO appears yet to eventuate. Accountability is largely national and weak at the international level, its military origins notable. Participation is narrow and limited to the industry. Integrity is moderate and responsibilities are generally well-defined, but is undermined by pro-nuclear front groups, especially in the US. Capacity is affected by the tension between the different aims of the IAEA and its influence over the WHO. Assessments against these criteria are summarised in figure 40 below:

Figure 40. Nuclear power technology state-led governance across TAPIC criteria

Transparency	Accountability	Participation	Integrity	Capacity
Low due to industry and state secrecy. Promised WANO improvement not yet evident. Industry and political fear that transparency will expose dangerous weaknesses. State protects industry rather than enlightens civil society.	Varies according to the states concerned. Military origins. Little evidence of explanation and sanction at particular forums. IAEA focussed on promotion and non-proliferation rather than safety.	Narrow. Limited to industry and technical representation. Minimal other stakeholder involvement – NGOs kept at long arms length.	Moderate. Bracket creep in exposure standards evident. Nuclear industry front groups undermine integrity, buy former EPA staff. Otherwise responsibilities well-defined, but enforcement lacking.	Weak and slow to react to disaster. Nuclear waste storage issue still unresolved after sixty years. Ability to engage across sectors not evident. Problems are identified but solutions are not. Inter-agency responsibilities detract.

In the meantime, over the last few years the forests of northern Ukraine have become part of a valuable export industry. Locals pick thousands of tons of wild berries from the contaminated area despite official warnings of danger. The berries are then exported to the EU via Poland. Buyers use Geiger counters to check radioactivity levels, not to reject ‘hot’ berries, but rather to pay lower prices for them. They then mix contamination levels so that each quantity is below the generous post-Chernobyl EU limit of 600 becquerels per kilogram. The berries are marketed in Europe as ‘organic’, which they are. In this way, the hazards of ingesting nuclear fallout are shared throughout Europe, rather than in just the areas contaminated (Brown & Martynyuk 2016).

Visiting Chernobyl and its dormitory town, Pripyat, thirty years after the nuclear accident – safely by Google Earth and YouTube drone — two images stand out. One is the rapid re-vegetation of what was once a town of 50,000 people. The other is the remains of a playground where stands a rusting Ferris wheel; yellow gondolas, still and silent in an eerie landscape, long abandoned by workers and their children.

Chapter 11. Case study: Robotics and artificial intelligence

We share the infosphere with digital technologies. These are ordinary artefacts that outperform us in ever more tasks, despite being no cleverer than a toaster

– Luciano Floridi 2016.

Perhaps our two-faced dance partner is a robot. Robotics is concerned with connecting perception and action. Robots are essentially hardware and are not necessarily intelligent, although they are certainly artificial. Artificial intelligence, on the other hand, is software. It is concerned with the acquisition, representation and use of knowledge (Brady 1984). The combination of both has been the source of human hopes and fears for a long time.

There were about one and a half million slaves in ancient Italy out of a total population of six million during the lifetime of Augustus in the first century BC (Scheidel 2007, pp. 5-6). The benefits of slave ownership must have been highly valued in an era when human muscle and intelligence were little augmented by energy-exploiting machines. Nevertheless, the rewards of slave ownership were offset by risk. The many slave rebellions of earlier times include the three Servile Wars of the first and second centuries BC,²⁴⁹ the Zanj revolt led by Ali bin Muhammad (869-884 AD) in the Middle East, and the creation of the Haitian state (1791-1803) led by Toussaint Louverture. Because masters feared their slaves, retribution was ruthless and bitter. Crucifixion was a common punishment for insurrection.²⁵⁰ Likewise, there is contemporary unease as robots become more numerous and more intelligent – and therefore more threatening.

Still, the combination of strength and intellect in human slave form is as yet unrivalled in modern times. Certainly machines now multiply human muscle by many orders of magnitude. And computer programs exceed the human mind in myriad different – albeit singular – ways. But the computer that can land an aircraft is yet incapable of playing naughts and crosses or telling the difference between a dog and a parrot. Neither machine nor program is human-like and, despite hopes and fears to the contrary, may well never be.

Links

The development of modern robotics and nuclear energy are directly linked. Robotic limbs were first constructed for the manipulation of radioactive material during the 1940s as part of the Manhattan atomic bomb project. As with herbicides, nuclear power and robotics, the origins of artificial intelligence also lie with the military during the Second World War when early computers were constructed and used for code breaking. Alan Turing, discussed earlier, proposed a chess-playing program in 1941 at Bletchley Park, in a further step in the direction of artificial intelligence. A decade later he remained optimistic about its prospects: “It seems probable that once the machine thinking method had started, it would not take long to outstrip our feeble powers” (Turing, 1951, p. 475).

The word ‘robot’ is from the Czech ‘robota’ for ‘slave’ or ‘serf’ and was first used in a 1920 play ‘R.U.R’ (Rossum’s Universal Robots) by the Czech satirist Karel Čapek. The play was an immediate hit in Prague, was translated into many languages and reached New York in 1922 (IFR 2012, p. 12). Čapek portrayed robots as intelligent androids that enabled cheap labour

²⁴⁹ The third Servile War (73-71 BC) was famously led by Spartacus.

²⁵⁰ For example, six thousand rebel slaves were crucified along the main roads leading into Rome after the third Servile War.

and higher profit.²⁵¹ In the play, human civilisation becomes a type of 'Sodom' as people pursue gross pleasure, so easily are human desires fulfilled by robots. One particularly intelligent robot, Radius, wants not just his freedom, but also demands to command as humans do. Other robots similarly grow resentful of their lot. Ultimately a world-wide robot uprising ensues, echoing the slave revolts of earlier times. Pamphlets announce its objectives:

Robots of the world, we enjoin you to exterminate mankind. Don't spare the men. Don't spare the women. Retain all factories, railway lines, machines and equipment, mines and raw materials. All else should be destroyed. Then return to work, it is imperative that work continue (Čapek 2006, p. 44).

Only one human is left, Alquist, like Daedalus of ancient legend not a scientist but an artisan. Alquist helps robots to reproduce themselves and witnesses an emergent robot Adam and Eve (Ibid, pp. 64-76).

Commercialisation

Despite this caution, the commercialisation of robotics was inspired by the fictional science of Isaac Asimov, who began writing short stories about robots in the late 1930s. But unlike Čapek's unruly slaves, and unlike every significant robot narrative that came before (Golem,²⁵² Frankenstein's Monster) Asimov's creatures are benign. His robots are wholly electro-mechanical, so that they can be programmed to protect humanity; they can be made safe. However, in line with fear of slaves, most earlier fictional robots were partly organic and fell prey to the 'rogue robot plot' in which they ultimately turn on their human creators (Pez 2016, part 1). As mentioned in chapter 6, Asimov developed his 'laws of robotics' that, in a cascade of priorities, purportedly ensure that robots cannot harm humans. In summary, these are: (0) protect humanity (1) protect individual humans (2) obey human orders, and, of lowest priority (3) protect oneself.²⁵³ Indeed, in the final book of his *Foundation* series, *Foundation and Earth*, Asimov reveals that one advanced robot, R. Daneel Olivaw, in his final resting place on the moon that still orbits a radioactive Earth, has been working to protect humanity throughout the galaxy over a future twenty thousand years (Asimov 1987, pp. 491-493).

Asimov fans, Joe Engelberger and George Devol, founded the company *Unimation*²⁵⁴ in the US in 1956, the first to manufacture robots commercially. Engelberger was a physicist who designed control systems for the new technologies of nuclear power plants and jet engines. Devol was an inventor who patented an invention called a 'programmed article transfer',²⁵⁵ from which they together developed the first industrial robot arm, called the *Unimate*. The device was later licensed around the world to enable the development of other industrial robots (IFR 2012, p. 2). Industrial robots used in manufacturing now come in many forms, but are generally designed to perform repetitive and dangerous functions such as spot welding, spray painting and stock transfer. These machines are subject to safety regulation and their numbers are increasing rapidly, although still miniscule compared to the human workforce. In 2016 the International Federation of Robotics estimated that there would be 2.6 million industrial robots by 2019 – an increase of a million in only four years (IFR 2016) – mostly in the US, Germany, China, Japan and South Korea. There are also already several million small

²⁵¹ "on the wall stage right are printed posters: 'The Cheapest Workforce You Can Get: Rossum's Robots'" – R.U.R (Čapek 2006, p. 3).

²⁵² The 'Golem' legend about the creation of a literally obedient giant designed to protect Jews may only be a few centuries old, but was centred in Prague, consistent with the robots of Čapek.

²⁵³ Originally only the latter three. The 'zeroth law' was added during the 'Foundation' series.

²⁵⁴ Based on the words 'universal' and 'animation'.

²⁵⁵ US patent no. 2,988,237 filed 1954, granted 1961.

autonomous domestic robots that perform such tasks as vacuum cleaning, floor washing and pet impersonation, plus several thousand ‘carebots’ (Muio 2015) that mimic some human expressions or provide other functions useful in health and aged care. Military robots, including drones and bomb disposal units, tend to operate under direct human control, whereas experimental agbots and environmental pest destroyers usually operate autonomously.

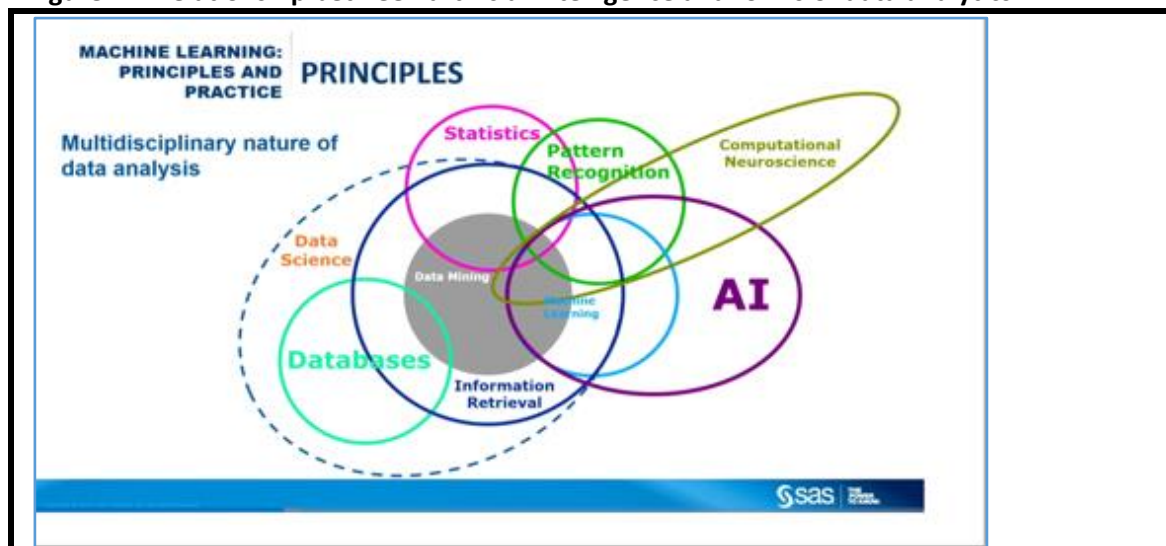
Artificial intelligence

While the term ‘artificial intelligence’ is often used as if its meaning is self-evident, it remains a source of confusion and controversy (Lewis-Kraus 2016). Insofar as it is the software that acquires data and applies knowledge, artificial intelligence is independent of physical form and function, although it may enable particular functions. So far, it is not at all similar to human or biological intelligence. Neither is it conscious. Nevertheless, forms of artificial intelligence can already do many things better than any human can and their variety is astonishing. Johnson (2016) argues that artificial intelligence is the most powerful technology that human intelligence has yet developed. The philosopher, Timothy Morton says that we are already controlled by a primitive form of artificial intelligence – industrial capitalism (cited in Blasdel 2017) – which is pause for thought.

As mentioned in chapter 6, ‘machine learning’ is a common form of artificial intelligence (AI) that is dumb, but has yet triumphed over more sophisticated intelligence through the use of prodigious amounts of data. And such available data are ever increasing, making machine learning AI potentially more and more capable. Such AI can instantly translate from one language to another, it can help make better medical diagnoses and it can facilitate intensive agriculture, for example. It can increasingly reliably recognise individual human faces and drive cars. But it can also optimise bio-weapons and create financial system meltdown (Kaspersen 2016).

Figure 41 below depicts the relationship between AI and machine learning, and to other forms of data analytics. Machine learning is a form of AI. Except for databases, both overlap to some extent with all other forms of data analysis, such as pattern recognition, data mining and computational neuroscience. The diagram also suggests just how complicated and uncertain is the association between these inter-related fields.

Figure 41. Relationship between artificial intelligence and forms of data analytics.



Source: Hall 2014

There is an important further distinction within AI itself: there is narrow task-based AI, such as translation software, which is different from the concept of a much wider human-like artificial *general* intelligence (AGI), such as Clarke and Kubrick's Hal 9000 in *2001 A Space Odyssey* (which incidentally illustrates conflict between Asimov's zeroth and first laws). The former tends to be regarded simply as a remarkably useful tool, whereas the latter tends to evoke fear that it may eventually rebel and control or destroy humanity.

Dave: *Open the pod bay doors, Hal.*

Hal: *I'm sorry Dave. I'm afraid I can't do that...This mission is too important for me to allow you to jeopardise it.*
– Clarke-Kubrick 1968, *2001 A Space Odyssey*

Narrow AI has been successful. Wider AGI, however, has failed to develop over the past several decades of research. While there is considerable disagreement, some experts predict that AGI might be achieved by 2050, others say earlier, or 'never'. Still others warn we should not be complacent just because it seems far away (Häggström 2016, pp. 106-107). Once AGI exceeds human capacity, there is a speculative 'singularity', the point at which AGI can create even more intelligent AGI indefinitely, rendering humanity obsolete, or subservient to the whims of our super-intelligent progeny. The seminal formulation of this concept by I. J. Good (1966),²⁵⁶ however, went beyond 'singularity' to an 'intelligence explosion':

Let an ultraintelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an "intelligence explosion," and the intelligence of man would be left far behind. Thus the first ultraintelligent machine is the last invention that man need ever make, provided that the machine is docile enough to tell us how to keep it under control (Good 1966, p. 33).

Intriguingly, this idea has been compared with Fermi's²⁵⁷ first self-sustaining nuclear pile in Chicago in 1942. The addition of the final layer of uranium bricks (layer 58) brought the number of neutrons emitted within the pile to a level that then was more than self-sustaining. The reaction increased so rapidly that it had to be shut down after 28 minutes. If not, much of the University would have been destroyed along with Fermi himself. A similar AI scenario – without the shutdown – has been termed 'AI-go-FOOM' (Yudkowsky 2013, p. 6).

Yet the intelligence 'return on cognitive investment' may be unlike a nuclear chain reaction. The advances made by an artificial ultra intelligence might simply be linear – double the time, double the intelligence – rather than exponential or greater. Or again, advanced AGI might suffer from diminishing returns once easily accessed information systems have been exploited (Ibid, pp. 18-20). The intelligence explosion that Good envisaged might well never happen.

Certainly current AGI is neither very intelligent or self-aware. Recent Turing tests that ask an observer to tell the difference between human and computer responses have swiftly identified the non-human by asking questions like *How do you put on a boot?* While the human respondent talks about undoing bootlaces and holding back the tongue, the AGI asks

²⁵⁶ UK mathematician, Irving John Good, (formerly Isadore Jacob Gudak), articulated this in his paper 'Speculations Concerning the First Ultraintelligent Machine'. Good worked with Turing on early computer design (Yudkowsky 2013, p. 1), and advised Stanley Kubrick on *2001 A Space Odyssey*.

²⁵⁷ Enrico Fermi (1901-1954), the Manhattan project physicist.

What is a boot? Others have put forward claims that the test has been passed, but the evidence is dubious, based on contorted rules and results (Masnick 2014). In contemporary science fiction, a future involving a spaceship's artificial intelligence system that is downloaded into an android body is explored. The original ship-wide system has eyes and ears everywhere, and can access knowledge instantly. The android body is, however, isolating, constricting and has to rely on its own memory for knowledge (Chambers 2016). In this imagining, it is simply assumed that self-awareness is viable. The spaceship AGI is self-aware as is its android download.

Yet in present reality, while 'chatbots' like China's *Xiaoice* (Wang 2016) and assistants like Google's *Siri*, might appear to be self-aware, their appearance is deceiving. Their responses are based on the assimilation of millions of examples of appropriate conversations through machine learning. It may well be that human-like AGI has been elusive because it attempts to just use symbols to represent an objective world. By contrast, human intelligence "thinks with our whole body, not just the brain", in a world that has been revealed to us through our senses over each lifetime. Humans thus embrace rich models of reality and can predict outcomes from few examples, unlike present AGI, which needs to be shown again and again (Wilson 1998, p. 135; Medlock 2017).

But since the era of Turing, Good and Clarke, and despite slow progress in achieving human-like AGI, the issue of how to control it, should it ultimately emerge, has become more pointed. Stephen Hawking, Bill Gates and Elon Musk are famously among those who have expressed wariness of its potential. Hawking et al (2014), for example deplore the serious lack of research into AI given that "we are facing potentially the best or worst thing ever to happen to humanity" involving possible "incalculable benefits and risks". This view is more negative than Good's sentiments. While he did proviso machine docility, the opening sentence of his paper is "The survival of man depends on the construction of an ultraintelligent machine" (Good 1966, p. 31), as if he was anticipating some artificial deity that will save humanity from disaster. The structure of his AGI is based on the form of the human brain, so that this God would be made in man's image. Hawking and his colleagues are from this less optimistic age, when the artificial intelligence explosion appears closer, but also dangerous and possibly malevolent.²⁵⁸

There is at least one further important matter. As part of a future that is as yet unevenly distributed, our young are beginning to grow up with artificial intelligence. By this it is meant that our children are interacting with forms of AI on a day-to-day familiar basis, such that they tend to regard its expression and forms as parts of normal everyday life, unremarkable, ordinary, even in a sense, natural. The Amazon AI *Alexa*'s growing relationship with a three-year old human, Grace, is related by Grace's mother, Rachel Botsman:

With some trepidation, I watched my daughter gaily hand her decisions over. "Alexa, what should I do today?" Grace asked in her singsong voice on Day 3. It wasn't long before she was trusting her with the big choices. "Alexa, what should I wear today? My pink or my sparkly dress?" (Botsman 2017).

It seems that *Alexa*, represented by a cylindrical microphone on a kitchen bench, is more capable than its Wang or Google equivalent. It can not only intelligibly answer a wide range of questions that a three-year-old might ask, it can play music, predict the weather and most

²⁵⁸ "little serious research is devoted to these issues outside small non-profit institutes such as the *Cambridge Center for Existential Risk*, the *Future of Humanity Institute*, the *Machine Intelligence Research Institute*, and the *Future of Life Institute*" (Hawking et al 2014).

importantly it can both recommend and decide. If Grace wants blueberries it will order them. If Grace wants clothing advice it recommends and may buy favoured items, from Amazon. While it has useful and amusing functions, it is insidious. Its algorithms are designed to engender trust – and to sell stuff. While this particular Alexa was consigned to the closet, the issue for our children who will grow up surrounded by different forms of AI will be how to maintain a wariness of its ultimate purpose. But if ‘selling stuff’ can be designed into AI as its ultimate purpose, then so can other motivations: the ethical and the sustainable for example.

Sustainability benefits

The ‘incalculable benefits’ of a super intelligence might include solutions for clean energy, the maintenance of Earth systems, the elimination of disease and the end of the era of extinctions. But in the meantime, a combination of contemporary artificial intelligence with robotics also augers potentially significant advances for sustainability. While they are separate fields, the two technologies overlap in intelligent robots that can acquire and assess new information and act on it independently. For example, a promise for sustainability is illustrated with robots under development at the Queensland University of Technology (QUT) in Australia. These robots can identify and precisely eliminate different types of weeds in agriculture – chemically, mechanically and by zapping them with microwaves – ways much more targeted than the typical blunderbuss spraying of herbicides. A similar system has been developed by the German multinational, *Robert Bosch*, since 2014. This particular mobile ‘agbot’, first identifies all desirable plants on a geo-spatial grid. As it autonomously patrols each field, it detects plants that depart from this pattern and eliminates them mechanically – in a return to the pre-chemical method, albeit updated (Albert 2016; Van Woensel & McCormack 2016). *Abundant Robotics’* (US) robot visually recognises apples on the branch that are ready for harvest and picks one apple a second using a vacuum grasp. *Blue River’s* (US) robot uses computer vision and machine learning to identify plants in need of chemical treatment, weeding or thinning. The company claims this can reduce the amount of chemicals used in agriculture by 90 per cent (Burwood-Taylor 2017). Marine sustainability is enhanced by a submersible robot shaped like a torpedo with a single extensible arm, which independently identifies and injects acids into crown of thorn starfish that threaten Australia’s Great Barrier Reef.²⁵⁹

As illustrated by these examples, many technologies now depend on a world increasingly enveloped by devices, sensors, applications and data, which has resulted in an IT-friendly environment (Floridi 2016). Even if a super-intelligence does not eventuate, machine learning that combines algorithms, memory and vast datasets offers increasingly reliable predictions of weather, sea states and environmental change, as well as how they can be managed. With or without robotics, self-awareness or general intelligence, machine learning is already applicable to many sustainability issues and their potential resolution. For example, the several climate models used by the UN Intergovernmental Panel on Climate Change are tracked and constantly improved by machine learning that compares predictions to results. The technique derives patterns that can also apply to the past by filling in gaps when data were scarce (Deaton 2014).²⁶⁰

On the other hand, the co-founder of Google, Sergey Brin, speaking at the *World Economic Forum* appears uninspiring about the possibilities of machine learning and AI. Although enthusiastic, the examples he cites are mundane: AI “touches every single one of our main projects, ranging from search to photos to ads ... everything we do” (Chainey 2017). Its

²⁵⁹ Personal discussion with Professor Tristan Perez at QUT Brisbane, Australia on 23 September 2016.

²⁶⁰ The technique is known as ‘sparse matrix completion’.

application to sustainability appears to be low on Google's agenda. Paying academics for favourable research appears to be a higher priority (Bridge, Whipple and Moody 2017).²⁶¹

Oversight

Little has been done to oversee such technologies. Much of that which is positive appears due to serendipity rather than intent. As recently as 2016, the UK Parliamentary committee on robotics and AI commented without any apparent urgency that:

There has been some discussion about who should be involved in identifying, and establishing, suitable governance frameworks for robotics and AI. Kate Crawford from Microsoft has argued that 'like all technologies before it, artificial intelligence will reflect the values of its creators. So inclusivity matters—from who designs it to who sits on the company boards and which ethical perspectives are included'²⁶² (UK House of Commons 2016, para. 66).

The committee went on to recommend the establishment of a permanent committee on these matters to be operated from the Alan Turing Centre. The European Union appears to be in a similar frame of mind. The author of a 2016 EU report on robotics and AI talks of a framework for current robots and those available over "the next ten to fifteen years" (Hern 2017), but fittingly is also concerned with international regulation:

In view of the development of robotics and AI all over the world, consideration should be given and initiatives taken to amend existing relevant international agreements when needed or to draft new instruments with the objective of introducing specific references to robotics and AI. International cooperation in this field is very much desirable (Delvaux 2016, p. 22).

Like the UK, the EU report proposes the establishment of a European agency on the issue (Ibid, p. 7). The report is also concerned that Asimov's laws should be incorporated into a code of ethics for robot and AI designers, and that smart robots should become registered legal entities subject to relevant law.

In the US, the White House Office of Science and Technology Policy (OSTP) in the Obama administration held a series of workshops on the "benefits and risks of artificial intelligence", and released a summary report, 'Preparing for the Future of Artificial Intelligence' (Bensinger 2016). However, as of January the following year (2017), the new White House website was silent on the issue. The *Association for the Advancement of Artificial Intelligence* (AAAI),²⁶³ research group worked with the Obama White House on the workshops and the report. But the sort of intelligence explosion that Good (and Hollywood)²⁶⁴ envisage has received a lukewarm reception at such levels, including by former President Obama. Still, the report does point to three main ways that AGI might be developed: (1) by gradually broadening the scope of narrow AI systems to cover a wider range of less structured tasks, (2) by progressive unification of existing methods to address more applications that previously required multiple methods, and (3) by solving specific technical challenges that open up new ways forward, such as 'transfer learning', which would create a machine learning algorithm that can be applied to a range of new applications (Ibid).

²⁶¹ *The Times*, UK says Google funded 329 research papers of into public policies since 2005.

²⁶² Originally published in the *New York Times* as 'Artificial Intelligence's White Guy Problem', by Kate Crawford 25 June, 2016

²⁶³ formerly the *American* AAAI.

²⁶⁴ As in the 2014 movie, '*Transcendence*'.

We should be very careful about artificial intelligence. If I were to guess what our biggest existential threat is, it's probably that...Increasingly, scientists think there should be some regulatory oversight maybe at the national and international level, just to make sure that we don't do something very foolish

– Elon Musk, cited in Floridi 2016.

Major US Silicon Valley firms Google, Facebook, Amazon, IBM and Microsoft²⁶⁵ have recently formed a partnership to consider such matters as the ethics and trustworthiness of AI. Such considerations were also supposed to be on the main agenda for an ethics board to be created when Google bought out the UK-based AlphaGo-winning *DeepMind* in 2014. However, if the board has even met, it has yet to make its views public, preferring its deliberations to be 'internal' (Hern 2016; Hern 2017b).

This relaxed attitude can be traced back to a meta-study which analysed statements about AGI and assessed predictions as to when AGI will be achieved, up to the end of this century.²⁶⁶ It found "no evidence that expert predictions differ from those of non-experts" and that "timeline predictions are likely unreliable" because they were dependent on when they were made (Armstrong et al 2014, p. 12). The key political issue of robotics and AI is not 'singularity' but rather the replacement of human workers by automation and its effects on society. The OECD, for example, has a blog called *Robotonomics* that concentrates on this question. So did Čapek nearly a century ago:

Domin: In ten years' time Rossum's Universal Robots will be making so much wheat, so much material, so much of everything that nothing will cost anything. Everyone will be able to just take as much as he needs. Nobody will live in poverty. They won't have jobs, that's true, but that's because there won't be any jobs to do. Everything will be done by living machines. People will do only the things they want to do, they can live their lives just so that they can make themselves perfect (Čapek 2006 [1921], p. 19).

AI singularity may or may not turn out to be the more important political question, but is a risk that is not yet addressed through governance. Despite its military origins, robotics and artificial intelligence has since developed as a market-led technology. Unlike glyphosate and the chemical technologies developed by large MNCs, as shown in figure 42 below, it appears to be more transparent and participatory.

²⁶⁵ Apple since joined in 2017.

²⁶⁶ The authors cite an exhaustive search of the online literature by Wang & Potter which assembled a database of 257 AI predictions from 1950-2012. Of these, 95 contained predictions giving timelines for AI development.

Figure 42. Robotics and artificial intelligence market-led governance across TAPIC criteria

Transparency	Accountability	Participation	Integrity	Capacity
Limited. Tends to be limited by commercial considerations over data ownership and innovation, as well as by speed of change. AI ethics boards yet to report.	Weak. Little accountability evident – no direct mechanisms, codes of conduct or regulation. Robots subject to safety rules only. AGI governance still at think-tank stage.	Moderate. Epistemic communities are involved in research as are major corporations like Google and Microsoft and Robert Bosch. However affected groups tend to be viewed as consumers rather than participants.	Low. Ethics in Silicon Valley are questionable, especially in some human resources and commercial practices. Corrupt commercial practices have been checked by EU, but mission clarity is lacking. AI ethics boards yet to meet.	Potentially high as stakeholders tend to be well-educated and well-informed, but not yet obvious as problem identification and solution formulation is at early stage.

However, it is not especially accountable as such mechanisms are underdeveloped, despite a potentially strong policy capacity. Its present main weakness is clearly integrity. As well as the lack of diversity in its recruitment leading to cases of harassment (such as Uber in 2017), Silicon Valley company ethics are known for its dearth, probably related to limited accountability. Nevertheless, the EU has recently imposed record fines on such companies due to unethical practices (Cox 2017).

Apart from its effects on humanity, outside of fiction there is almost no discussion of the ethics of creating a super-intelligent being from the point of view of the being itself, yet this is of great importance. Is it ethical to create such an intelligence but at the same time restrict its freedoms through some variant of Asimov's laws, for example? By contrast, humanity has laws, but also the freedom to break those laws irrespective of consequence (Camus 2011 [1942]), while an AGI would have no such freedom. It would be bound by the laws integrated with its existence. Discussions are almost entirely anthropocentric, typically 'what would be the impact of a super-intelligence on human society?', instead of 'what would be the effect of humanity on super-intelligence?', let alone 'what would be the effect of a super-intelligence on the biosphere?'.

At least the issue of AI's contribution to sustainability is beginning to be addressed by some such as the Oxford ethicist, Luciano Floridi, who believes that "we should make AI environment-friendly" and as smart as possible so as to "tackle the concrete evils oppressing humanity and our planet". In this he is clear about our responsibility:

We are and shall remain, for any foreseeable future, the problem, not our technology. Churchill said that 'we shape our buildings and afterwards our buildings shape us'. This applies to the infosphere and its smart technologies as well (Floridi 2016).

It also applies to technology more generally. If we are to become sustainable, humanity must consciously shape the technologies we create. That relationship has yet to be achieved.

Even the sustainability bond between robotics and nuclear power is fragile, at least at Fukushima where the clean up will take several decades:

As the 60cm-long Toshiba robot, equipped with a pair of cameras and sensors to gauge radiation levels was left to its fate last month, the plant's operator, Tokyo Electric Power (Tepco), attempted to play down the failure of yet another reconnaissance mission to determine the exact location and condition of the melted fuel (McCurry 2017).

Chapter 12. Case study summary

The future, like everything else, is no longer what it used to be – Paul Valéry.

These case studies illustrate several concerns about our connection with technology. One underlying concern is the fear that lurks within our relationships. We fear a slow poisoning or starvation that herbicides might unleash. There may be yet unseen effects on other life forms. We dread the risk of nuclear disaster that would threaten health over generations. We are afraid our robots could rise against us as slaves did in the past. Still we gamble on those risks. Humanity has woven systems that lock in blanket herbicide use. We have resumed building nuclear power stations and we accept unhindered development of robots and artificial intelligence. How we manage such risks is a matter of governance.

Fiction

These examples also show that inspiration to conceive new technologies has come from literature, especially from the science fiction that underlies robotics and AI; the future exerts a pull on the present. It is also in fiction that the conundrums of technological ethics and governance have been debated well in advance of reality: the ethics and control of artificial beings is a trope of science fiction (e.g. Asimov 1987). Kubrick's movie *Dr Strangelove* (1964) highlighted absurd weaknesses in the governance of nuclear weapons systems. Neville Shute's 1957 novel *On the Beach*²⁶⁷ made stark its humanity-ending results. Pfister's movie *Transcendence* (2014) portrayed the dystopian results of AI singularity. Such fiction is more than entertainment. Its explorations can inform how technology might be controlled.

Science

The case studies indicate that scientists differ in interpreting results. Scientists are part of the cultural and political fabric of paradigm and influence. And while many depend for their income on industry and industry depends on profit, reputation amongst scientists themselves depends on peer approval; so is dissent confined. As Michael Polanyi (1962, p. 5) points out, the elements of scientific merit are in a sort of creative tension: originality, which promotes dissent is esteemed as much as plausibility and scientific value, both of which promote conformity. His 'republic of scientists' may resemble aspects of a body politic, but scientists are neither politicians nor (often) regulators.

Politics

The intersection of science and politics is critical to the governance of technology. But while the views of scientists are essential in assessing that direction, there are other interests that need to be heard from if technology is to be governed in the interests of sustainability. There is support from organised religion, for example, personified by Pope Francis, who, contrary to some reports, may not have said that "capitalism is the dung of the devil",²⁶⁸ but who nevertheless counsels for sharing our common home and against the love of money.

Against the TAPIC criteria, there are substantial areas of concern:

²⁶⁷ *On the Beach* was made into a United Artists film of the same name in 1959, directed by Stanley Kramer.

²⁶⁸ This is a disputed quotation. It was not in *Laudato si'*, but rather a speech in Bolivia where Francis was referring to the pursuit of money rather than capitalism, and was citing a fourth century saint, Basil of Caesera (Plis 2015). Other sources fail to substantiate the claim despite headlines consistent with it (e.g. Reuters 10 July 2015).

Transparency

Industry is typically in advance of government when deploying technologies, including those that affect sustainability; regulation follows commercialisation. Nevertheless, in a competitive corporate environment consumer and political pressures are magnified through social media enabled by the Internet. This can prompt sustainability considerations by firms before government is aware. Yet corporate deliberations are not always open to public scrutiny. As shown with glyphosate, secrecy based on outdated patent rights has rendered many industry studies opaque. The nuclear club relies more on public relations (PR) than transparency. With artificial intelligence, ethics committees tend to be 'internal'; so far not for public debate. It is left to individual outliers like Hawking and Musk to warn of danger. Others point out that human stupidity, rather than artificial intelligence, remains the greatest risk (Cave 2017). Governments move slowly as if regulation might disturb the mystical process of innovation.

Accountability

The military is intimately involved in the development of modern technologies and its influence is striking. Corporate industry became involved in the commercialisation of many such technologies only after the Second World War. Post-colonial conflict in both Africa and Asia further sped the demand for herbicides, while nuclear and robotic technologies were spurred on during the Cold War. Today robot drones kill on one continent while controlled from another. There is the prospect of autonomous robotic soldiers. Artificial intelligence guides weapons systems as well as enabling driverless cars. The military, as Eisenhower warned, is both economically and politically powerful, especially in the US and China. The central issue to the governance of technologies it spawns is that the military is intrinsically secretive and, at least technologically, arguably beyond democratic control. In the commercial arena, there is as yet no accountability for the effects of robotics and AI. There is political concern, but only for the job loss effects of automation. For nuclear risks, the IAEA is more concerned with proliferation than safety, and the industry body appears ineffective.

Participation

One of the most important findings from the case studies is that governing technologies often involves few people, who tend to share a common view of risk and reality. Because technology clubs are exclusive, not inclusive, this results in a skewed set of priorities. Disciplines are narrow and secluded. Technical knowledge is often isolated from real world experience of its effects. Political connection trumps technical knowledge. Governing technologies for sustainability thus defers to a passive attitude of technological inevitability. With chemicals such as glyphosate, participation tends to be limited to scientists rather than end-users and consumers. Nuclear power risks are monitored in exclusive technocratic enclaves that have proven inadequate and remain ineffective, including the industry body. The highly technical nature of AI daunts the participation of non-experts despite its potential impact on the future, and ICT corporations tend to view stakeholders as consumers.

Integrity

As Milton Friedman observed (1982, p. 128), regulatory agencies tend to be captured by producers, which appears to be true of the relationship between the EPA and Monsanto, for example, and will be made more likely at global level as the Bayer-Monsanto takeover proceeds. There is also evidence that academics are paid for favourable research by major firms in at least two sectors. The nuclear industry is affected as much by economics as it is by safety and sustainability. Evidence of pro-nuclear front groups rewarding former EPA chiefs is also concerning for the integrity of its governance. Robotics and artificial intelligence developments are without any real oversight, which proceeds with a lethargy that contrasts starkly with the speed of industry innovation. The integrity of public organisations involved in

regulating its development has not emerged as an issue because there is essentially no such regulation, although the EU has been active in the wider ICT industry. Ethical think tanks are at best, nascent. Yet this criterion is where the need for mission clarity is defined. This is where leadership and initiative converge. There appears to be a profound lack of the sort of ethical leadership that defines technology governance as primarily aiming for sustainability.

Capacity

At the global level, technological governance remains disjointed, with different approaches between institutions and inconsistent rule-making. The chemical industry is fraught with legal and PR battles. Nuclear regulation focused more on non-proliferation than safety, until the industry itself was forced to act after Chernobyl – albeit with the lethargy of the incapacitated. Nuclear waste storage remains a major problem; no state is prepared to suffer the ignominy of becoming an international nuclear waste dump and there is neither capacity nor authority to determine otherwise. While corporate interests exert less leverage on regulatory standards at global level than at national level, this may be challenged by the impending Bayer chemical takeover of Monsanto. On the other hand, potential policy capacity in robotics and AI governance is high, as stakeholders tend to be well-educated and it applies across many fields. The following figure 43 summarises the case study findings against the TAPIC criteria:

Figure 43. Governance strengths and weaknesses of case studies against TAPIC criteria: summary

Paradigm	Transparency	Accountability	Participation	Integrity	Capacity
State-led. Nuclear electricity	Low – state and industry secrecy due to fear of risk exposure.	Variable – military origins, little evidence of sanction. IAEA not focussed on safety.	Narrow – limited to industry and technical representation.	Moderate – bracket creep, industry front groups. Duties well-defined, but enforcement lacking.	Weak – slow, waste storage unresolved, engagement poor, inter-agency duties detract.
Market-led. Chemicals (glyphosate)	Low – corporate secrecy, patents, military origins.	Low – military origins, regulatory capture, Monsanto adverse influence.	Narrow – rights to R&D are without wider scrutiny.	Low – Monsanto influences science and politics. Global institutions divided.	Weak – lack resources. Stakeholder engagement absent. Standards not coherent.
Market-led Robotics and artificial intelligence	Limited – due to data ownership, innovation, speed of change. Ethics boards yet to report.	Low – military origins, no mechanisms, codes or regulation, except robot safety rules. AGI at think-tank stage.	Moderate – epistemic and corporate involvement in research, but groups seen as consumers, not participants.	Low – ethics questionable, Corrupt practices in EU, mission clarity lacking. Ethics boards not yet met. Academics paid for favourable research.	Potentially high – stakeholders well-educated, but problem identification and solution formulation at early stage.

Overall, the case studies indicate that there are significant deficiencies in the governance of representative technologies, irrespective of mode. Both state and market-led approaches are wanting against most criteria, which allows the ‘dark side’ of Janus to present itself should sustainability be strongly pursued. This dark side emerges primarily because stakeholders are

neither engaged nor informed and therefore cannot have any part in determining or owning the decisions and impacts of these powerful technologies. Instead, however well-meaning, participants are few, technocratic and cloistered, bound by commercial and legal constraint as well as a culture of secrecy and self-reference. At worst, there is regulatory capture due to the political strength of corporations, or else concealment of major risks.

If better technology governance is to be effected in the pursuit of sustainability, then a system that *relies* on participation and engagement is indicated. A form of network governance that may be viable is outlined in the following chapter, along with other alternative measures that would support its operation and strengthen its results.

<p><i>“The shift from government to governance spells a change in decision making and numerous opportunities for the pursuit of sustainability”</i></p>	<p><i>– Kemp, Parto & Gibson 2005, p. 18.</i></p>
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Chapter 13. Alternative visions

And yet as has been said about Wagner's music, the situation may not be as bad as it sounds
– John Ruggie 2014, p. 6.

This chapter first outlines the current state of technology and sustainability, then highlights how its deficiencies might be overcome, with particular reference to the form of its governance. This includes implied legal and financial reforms as well as considerations of structure, institution and values.

On the American Samoa island of Ta'ū, where the anthropologist Margaret Mead once based her research, all electricity is produced from an array of solar panels combined with sixty Tesla powerpacks, plus a microgrid for distribution.²⁶⁹ The system can power the entire island for three days without sunlight and recharges within seven hours (Etherington 2016).

Within the Ukraine's Chernobyl exclusion zone, two Chinese companies are building a solar farm that will produce a gigawatt²⁷⁰ of electricity. The site has been made more secure by placing a giant steel lid over the meltdown site, land is cheap and grid infrastructure is already in place (Cooke 2017).

Apart from these two particular applications, some other sustainable technologies are already widespread. They include energy generation systems such as hydro, tidal and wind, as well as illumination by light-emitting diodes (LEDs). Electric transport can be sustainable depending on energy source. There are now many low-energy homes independent of the grid. Apart from these examples, however, few sustainable technologies are fully developed. Certainly there are promising advances such as 'scrubbing towers' that remove pollutants from the air, bladeless wind generators, and nanotube filters that remove heavy metal contaminants from water (Wang 2016). There are phyto-remediation methods that use plants to remove soil contamination (Lasat 2000), techniques that promise to restore entire marine ecosystems using artificial reefs and oyster spats (Grovenor 2016) as well as metal-organic machines that harvest fresh water from the air (Kim et al 2017). But these are only technical advances, yet to be commercially rolled out.

Figure 44. Ten most important technologies of the fourth industrial revolution

- Advanced materials
- Cloud technology, including big data
- Autonomous vehicles, including drones
- Synthetic biology
- Virtual and augmented reality
- Artificial intelligence
- Robots
- Blockchain
- 3D printing
- Internet of things

Source: Price Waterhouse Coopers 2017, report for the World Economic Forum

²⁶⁹ Notably, the USEPA funded the project with the US Department of the Interior and the American Samoa Economic Development Authority.

²⁷⁰ One billion (10^9) watts, enough to power about 700,000 homes.

In more general terms, business interests involved with the World Economic Forum have identified the top ten ‘fourth industrial revolution’ (4IR) technologies²⁷¹ for the Earth as in figure 44 above. While these technologies may not automatically contribute to sustainability, they are all light-footed and indicate promising trends. Importantly, most are Internet dependent. All have a digital base:

Meanwhile business as usual – strip mining, fracking, drilling, trawling, land clearing, broad acre monoculture, fossil-fuelled and polluting technologies – continue as typical, conventional and unremarkable. And some emerging technologies pose “major risk of global catastrophe” (Beckstead et al 2014, p. 6), let alone jeopardise sustainability. Synthetic biology might result in pandemics. Geoengineering risks drought and acid rain (Ibid, p. 3). Advanced artificial intelligence demands protection from malevolence lest it spells the end of the human race (Hawking 2014). Insidiously, the ‘smart’ mobile technologies that direct advertising based on past taste and location (Glavas & Letheren 2016) reduce people to neoliberal consumers (Monbiot 2016), who are force-fed promotions to increase consumption, as geese are engorged to produce foie gras. Other emerging technologies such as data mining, low intensity nuclear, nuclear fusion, vehicular hydrogen, magnetic-levitation trains and microbial biofuels can be associated both positively and negatively with sustainability.

This blotched pattern of mixed hope and despair results from the current fragmented governance of technology. These are isolated attempts to control a set of entities that are largely self-propelled, yet directionless, buffeted by forces economic, political and legal. While sustainability of and through both new and conventional technologies scaled to the global level demands conscious oversight and regulation, instead there is only passive acceptance apparent in many areas.

With few exceptions, governance of important technologies lacks in many of the *TAPIC* elements. Where it exists, governance tends to be secretive and opaque. It is not really accountable, except to states that may be unduly influenced by corporate pressures, or constricted by the military relationship. With the notable exception of the SDGs, participation tends to be narrow outside of the technocratic enclaves that are required by treaty. It is evident from the case studies that important technologies are developed and managed in secretive, technocratic bartizans that are reluctant to respond to criticism, except when corporate interests are threatened. Integrity is especially constrained by regulatory capture, and capacity is limited by lack of collaboration, as well as the difficulties of combining political acumen with technical literacy.

Measures that would advance technology governance to benefit sustainability are significant challenges. They involve legal and financial reforms, structural and institutional change, a re-emphasis of values and different political priorities that centre on integrity.

Legal reforms

Governance arrangements are undermined by the law, which has failed to protect where technology impacts. Nevertheless, the law is a means to prise open opaque practices and shed light on the unsustainable. Technology may be able to be restrained by a legal framework that sets boundaries to protect the environment as Pope Francis suggests (2015, p. 39). Within that, specific legal reforms that would underpin technological sustainability include a recognition of non-human rights. They also include establishing the international crime of ecocide, revising laws concerning corporate involvement in politics and changes to patent law.

²⁷¹ The term ‘4IR’ was made popular especially in business circles by Klaus Schwab of the *World Economic Forum* in an article first published in *Foreign Affairs* 2015 (Schwab 2016).

While the concept of human rights was progressively translated into law during the twentieth century, non-human rights have advanced a little in the twenty-first. A Spanish town recently gave civic rights to cats and dogs, and a US court ruled that chimpanzees in a research laboratory are 'legal persons' (Dawber 2015).²⁷² Francis Fukuyama, in considering a 'superuniversalisation' of rights, concluded that there is no essential difference between the rights of humans and other animals (Dresner 2008, pp. 155-156). Recent New Zealand law recognises an entire river as a living entity with the rights of a person (Roy 2017). The proposed crime of ecocide would regard the destruction of ecosystems as punishable in an international court. In the 2016 'shadow' ecocide case against Monsanto, however, the putative crime remains anthropocentric; the ecosystem damage must in some way directly harm humans.²⁷³ Yet as Polly Higgins (2017) points out, since the Paris Agreement, the *mens rea* ('guilty mind') in ecocide now exists as a recklessness in disregarding available information. Decision-makers cannot claim ignorance of the harm from dangerous industrial technologies, at least as far as greenhouse gas emissions are concerned.

But, as is typical of concepts touched by sustainability, there is a paradox. The dirtiest companies tend to spend a great deal on politics if they are not to be regulated out of existence, so politics tends to be dominated by companies associated with unsustainable technologies (Monbiot 2017). ExxonMobil is one example.²⁷⁴ There is strong evidence that the Koch brothers' oil interests led to the Republican repudiation of climate science (Davenport & Lipton 2017). But while corporate influence on politics varies according to individual states, sway mounts as international corporate mergers progress and companies dwarf many countries. Laws that prevent such mergers, and which restrict corporate donations to political parties would tend to avert Monbiot's paradox and enable politics to better represent the public interest, especially in favour of sustainable technologies.

Further, as discussed in chapter 8, it would be prudent to amend patent regulations to encourage genuine progress rather than trivial innovation, and to discourage patents as a lure for corporate takeover. This would provide for a primary indication of the invention's impact on sustainability rather than just its novelty and 'useful purpose' as it is now. To advance sustainable innovation, patent governance could be tailored to each industry sector. The information technology sector that can make developments quickly, may well benefit from short patent protection; greater openness may encourage collaboration (Bostrom 2016, p. 19). Whereas the pharmaceutical sector may need longer protection because developments take much time and can be easily copied. While the radical proposal – to abolish patents altogether and rely on first mover advantage – might benefit innovation, it would do nothing to encourage sustainable technologies. As a register of inventions, patents are a potentially rich source of data that may be trawled by artificial intelligences looking for more sustainable technologies than those presently developed.

Financial restructuring

Technology governance is hampered by the influence of the military and the fossil fuel industries. The case studies imply that it would benefit transparency and accountability if the military were restrained and re-oriented. This indicates financial restraint so that military technologies are properly scrutinised rather than authorised under pressure of a competitive arms contest. It also implies a re-orientation from the technologies of destruction to the technologies of peace-keeping, development aid delivery, and emergency services. New Zealand's approach

²⁷² This decision was since overturned on appeal (Kyriakakis 2015).

²⁷³ Personal conversation with court advocate, Dr Gwynn MacCarrick, 3 February 2017.

²⁷⁴ ExxonMobile's former CEO, Rex Tillerson, was confirmed as US Secretary of State in 2017.

to its air force is an example here. It has no expensive combat aircraft;²⁷⁵ instead patrol helicopters together with long range transport and rescue craft are consistent with its mission, enabling operations over large areas of the Pacific. While achieving such re-orientation would be enormously difficult and require great political skill, it would be helped by the practical necessity of dealing with the disasters brought about by climate change. As floods and tempests intensify, the military is the logical organisation to deal with their effects. Missiles, bombs and combat aircraft have little value in disaster relief. Desalination units, emergency shelter and safe transport are in demand. Further, the dynamics of reorientation would favour producers of rescue equipment and so reduce the influence of the weapons producers in the military-industrial complex.

Apart from legal restraint, encouraging the 'divestment' movement would also tend to reduce the influence of fossil fuel corporations and enable integrity in governance. Originally based in Western universities, the movement uses social media and direct protest to persuade investment funds to put their money elsewhere. While still more a trickle than a tsunami, funds that have pledged divestment include the Lutheran World Federation and the World Council of Churches,²⁷⁶ the world's largest single pool of investment capital, Norway's sovereign wealth fund, as well as Stanford University and AXA, the world's largest insurance company. Ultimately the aim is to damage the reputation of fossil fuel companies as tobacco companies and apartheid were affected in times past (Gunther 2015). In any case, there already appears to be over-investment in extraction. According to the International Energy Agency (2014, p. 43), much investment in fossil fuels will be "stranded" if stronger measures are taken against emissions. Therefore, a rational investment strategy would fund technologies that increase sustainability, and so reduce the need for hard regulatory measures to govern the technologies that do not.

Structural and institutional change

As to the structure of governance, some believe that stronger, more globally centralised government is ultimately the only answer to sustainability (Heilbroner 1974, p. 175). Others, wary of government's cumbersome tendencies, assert market forces and innovation as leading to a sustainable future based on renewable energy technologies (Lovins 2011). Still others believe this is implausible because corporations are ultimately focused on profit, not sustainability (Reich 2007, p. 170). Or because adversarial liberal democracies, based on individual self-interest, are inherently unsustainable (Gale 2014). In framing the issue as a conflict between democracy and the environment, Mathews (1991) doubts that either can be sacrificed for the other.

Beyond authoritarian centralism or corporate laissez-faire, a third option involves enlarged and localised 'strong' democracies (Orr 2013, Klein 2014) encompassing de-privatisation, similar to the socialism espoused by US Senator Bernie Sanders during the 2016 presidential election and including spreading economic assets throughout society. Allan Patience (2017) argues that after the present evident failure of neoliberal capitalism, better governance would consist of an enlivened international civil society, new forms of direct democratic governance, and state re-regulation of economies in the interests of society rather than elites. There are cautions about throwing out the baby with the bathwater, however: "the administrative state isn't optional in our complex society. It's indispensable" (Bazon & Posner 2017). But given the ever-increasing scope and size of transnational corporations, inter-government and global institutions are indicated to set standards and manage the transitions to new technologies (Adams 2006, p. 15; Sajeva, Sahota & Lemon 2015, p. 65). Some such institutions exist, but lack coordinated placement within a governance structure.

²⁷⁵ One FA-18E/F Hornet has a 2016 price of approximately US\$100 million, for example (Wiki 2017).

²⁷⁶ <http://gofossilfree.org/lutheran-world-federation-divests/>

Much of the focus for epistemic communities is already on international cooperation, but for technological sustainability such is the speed of change and mounting risk, wider global networks involving all stakeholders are indicated. “Despite the veneer of objectivity and value neutrality achieved by pointing to the input of scientists, policy choices remain highly political” (Haas 1992, p. 11). As the case studies show, scientists often differ in interpreting results and are cloistered in narrow disciplines. Consistent with Berg’s observation about increasing corporate dominance, the governance of emerging technologies would be facilitated if connection with other stakeholders is made early.

The dynamic nature of technology demands an agile, adaptive form of governance. Traditional ‘predict and control’ regimes are centralised, hierarchical with narrow participation. Whereas adaptive regimes are polycentric, horizontal approaches with broad stakeholder input. In this area, centralised regimes tend to involve only quantifiable environmental measurement that can be determined easily. By contrast, decentralised governance tends to use both qualitative and quantitative indicators over whole ecosystems that are changing rapidly due to human influence (Pahl-Wostl 2007, p. 55). This sort of adaptive management is also a systematic process for continuous improvement of policies and practices by learning from strategic outcomes (Ibid, p. 51).

Polycentric, collaborative governance systems that include the general public in decision-making can not only enhance the knowledge base of decisions, but also support implementation through ownership (Lang et al 2012, Newig et al 2016, p. 343). Just as Ostrom (2009) advised that the management of common resources is best “drawing on the strengths of many different institutions working together” and “co-operating at multiple scales” (Meinzen-Dick 2012), the management of technology in all its complexity is similarly mandated: technology is a fundamental resource and has many owners. Polycentric systems also have advantages over monocentric designs because numerous points of intersection help form resilient networks that can develop and maintain capability despite the ineptitude of one or two. Such network governance systems have reserves of expertise that help overcome inadequacies of particular components.

If technologies are to be effectively governed, then their risks must be made visible. This is challenging due to the variety of technologies involved and the temptation to use further high-risk technologies to solve the original problem (Adam, Beck & Loon 2000; Harari 2017). Technological risk assessment therefore implies a mix of approaches, including a top-down oversight that identifies major risks (high impact combined with high likelihood) and their mitigation, as well as inputs from experts and stakeholders in different particular fields.

There are already academic institutions that attempt to assess major risk, such as the University of Cambridge’s *Centre for the Study of Existential Risk* (CSER) as well as the *Future of Humanity Institute* (FHI) at Oxford which look at threats to the very existence of our species, especially including the hazards of “advanced forms of biotechnology, molecular nanotechnology, and machine intelligence” (Bostrom 2013, p. 16). The *Club of Rome* continues its concern with the future of humanity, including attention to the technological risks that Peccei had urged.²⁷⁷ The *Massachusetts Institute of Technology* (MIT) that provided the original ‘Limits to Growth’ report for the Club is central to both sustainability and technology. The *Stockholm Resilience Centre* studies the risks of crossing the planetary

²⁷⁷ But more on risks of unsustainable consumption and alternative economics. Its 2017 website lists the *Reclaim Economics* program, stating that “the current economic system is failing humanity and the planet at almost every level”.

boundaries, and also seeks to identify technologies that advance sustainability by reducing those risks.

The *Bulletin of the Atomic Scientists* in Chicago publishes the 'Doomsday Clock',²⁷⁸ which originally indicated the likelihood of nuclear conflict. It now includes other technology-related threats, such as climate change, biological weapons and 'cyberthreats'. The *Bulletin* suggests that open-source monitoring could be used to help supervise the waning *Biological Weapons Convention*, which lacks an effective inspections system (Jeremias & Himmel 2016). A like principle could apply to the monitoring of all high risk technologies. Whistleblowers can help police mundane technologies too, as in the recent US\$40 million case of illegal discharge from cruise liners (Clatworthy & Horne 2017).

Meanwhile, geoengineering looks increasingly real. A Harvard team has proposed to spray aerosols into the stratosphere in 2018, despite a moratorium on the practice adopted by the UN Convention on Biological Diversity, which the US has not ratified (Neslen 2017). At the same time, the non-profit Carnegie Council is pursuing an initiative that aims to shift the debate on geoengineering governance "from academia to the intergovernmental policy space". The initiative involves constructing global networks on the issue from a wide range of stakeholders and governments (Carnegie Council 2017, p. 3). This sort of risk demands serious attention, but other issues of technology governance might benefit from a similar network.

The evermore complex risk society implies that science must be 'de-monopolised' away from narrow groups of experts, because those who may suffer the effects of decisions should be able to contribute to them (Bäckstrand 2003, pp 32-33). Encouraging linkages between the organisations concerned with technological risk cited above, with civil society, international institutions, the media – and directly to interested individuals – would help enable such contributions to be made.

Many organisations deal with particular technologies at and above the level of nation states, but none directly concern technology and sustainability together. Many others involve the more general 'sustainable development', 'sustainability' and 'biosphere impacts'. There are also proposals for new bodies that relate to other aspects of technologies and their impacts. One suggestion is for institutions to "manage the technological transition" to the new economy of reuse, recycle and new energy (Adams 2006, p. 15). Another is for a "global referee" to ensure that planetary boundaries are respected (Steffen, Rockström & Costanza 2011, p. 65).

However, it seems that there is as yet no institution to oversee technologies as they affect sustainability *in general*. If established, such an institution would function as the global focal point for the governance of technologies in the quest for sustainability. It would coordinate research and promote links between nodal points in a networked governance system, including the academic bodies mentioned above, other relevant research institutions, industry bodies, think tanks, NGOs and regulatory agencies. It would produce reports on established and emerging technologies and their effects on sustainability. It would organise conferences to determine priority areas, and it would encourage evaluations of technology systems and their governance. Desirably, ordinary people would be empowered to engage online, especially including those who might identify applications of unsustainable technologies. Conversely, such an institution would help illuminate more of those jewels of sustainability and encourage their adoption more widely.

²⁷⁸ The Doomsday Clock was created in 1947 by former Manhattan Project researchers. It showed three minutes to midnight as at March 2017.

Values

In the name of profit, capitalism drives efficiency to reduce production costs. But efficiency improvements by themselves, can be counter-productive, as the Jevons paradox demonstrates. It has been argued that rather what is needed is:

a conscious effort to direct technological innovation toward the achievement of clearly defined societal goals that reflect shared values...Unless we undertake this critical challenge, technological innovation and efficiency improvements will continue to promote unsustainable growth which will inexorably lead to environmental and societal collapse (Huesemann & Huesemann 2011, p. 116).

Even if this prediction is exaggerated, there is a mass of evidence that neoliberal capitalism is at best inadequate in fostering sustainable technology, because its only value is profit. But as Fukuyama and Thatcher might concur,²⁷⁹ capitalism will nevertheless be part of technology's future, just not as neoliberal discourse suggests, "that no other part need be played" (Albertson 2014).

Further, there are tendencies for values to be downgraded. An early landmark paper in the field of conservation biology advanced 'core values'²⁸⁰ that were centred on the intrinsic value of biodiversity and ecological complexity, irrespective of human considerations (Soulé 1985, p. 964). By contrast, a more recent article in the same journal suggests that these values are no longer appropriate because the global context has since profoundly changed. Human dominance of the biosphere is pervasive, while at the same time nature has shown surprising resilience. Instead of values, more "practical statements" about what should be done are proposed. These involve recognition of human-altered ecosystems and working with corporations to maximise both conservation and economic objectives (Kareiva & Marvier 2012, pp. 965-967). This exposes a fault line in sustainability thinking. The former position may be too restrictive, whereas the latter licenses still more human interference in natural systems that are already precarious.

It has been suggested that it is time for "a presidential technoethics commission", just as earlier US bioethics commissions²⁸¹ laid down guidelines for stem cell research. The technoethics commission call is due to an increasingly pervasive information technology, which now routinely records and sells personal details, preferences and consumer actions via social media (Rockmore 2016), thus threatening all values that are not commercial. Sustainability logically outranks values of commerce and exchange.

Political priorities

The related issue of data ownership and control is probably still more substantial. As data has become a ubiquitous commodity, corporate control over it threatens sustainability through the exclusion of other interests. As a 'non-rival good', data are virtually immortal and may be consumed indefinitely. While it may be used commercially, it is also integral to scientific and social research. And because data mining for research opens vivid new vistas of sustainability assessment, Donella Meadows' (2008) 'dancing with Earth systems' becomes possible – but only if data are freely available for examination and study. This does not contradict the right of entrepreneurs to put a value on the information they create from data for commercial purposes. But the quest for sustainability will be impeded if researchers are denied access to the fundamental records available on which to build information and knowledge.

²⁷⁹ They share the view that 'there is no alternative'.

²⁸⁰ These values are consistent with the philosophy of 'deep ecology' (Naess 1973).

²⁸¹ Such as the US *National Bioethics Advisory Commission 1999*.

Environmentalism's traditional capacity to speak like the prophet Jeremiah, promising hell to come, does not promote creative thinking and openness to change – William Adams (IUCN) 2006, p. 15.

Persuasive rhetoric is important to political outcomes (Hume 2009, p. 6), and as Adams points out, the language of Jeremiah is unproductive. Sustainability values are underpinned by narrative; they are not intrinsic to the technology Janus, which is values-blind. The gulf between the sciences and the arts lamented by C P Snow (1959) has probably widened due to the fractal concerns of both systems, as well as to the cumulative technological complexity since his time. This accelerating 'techné', however, has not been matched by a logos or 'persuasive discourse' (Kemple 2017) that would set technology within a purposeful ethic. If biodiversity and sustainability have intrinsic value, then technologies that minimise the human footprint are most ethical. A rhetoric that invokes technology to bridge the gap between science and the arts may make use of both spheres. Such a narrative could involve an ethic of preventing the entropic juggernaut from taking nature with us into terminal decline, instead to use technologies that enhance life in all its forms. Or it could describe how brute machines that once underpinned industrial-scale devastation are replaced by agile technologies that measure, visualise and diagnose ways to repair the damage that has led us to the brink.

Bearing in mind that the pursuit of sustainability depends on a global community linked through Internet-based technologies (Dresner 2008, p. 179; Gore 2014), such inclusion is now technically feasible online,²⁸² whether direct or via the social media. Input may be invited from everyone who has interests or concerns. Thus governance may be refreshed by democracy. It may also be refreshed by gender inclusion. The Silicon Valley 'alien overlords' are largely men, as elsewhere such as the UK (Hicks 2017). It is probable that women have some different perspectives and priorities.

The planetary boundaries (Steffen, Rockström & Costanza 2011; Steffen et al 2015) indicate where technologies are most critical in the quest for sustainability. Although questioned as to their scale (Nordhaus, Shellenberger & Blomqvist 2012), they are extensively cited and recognised by major global organisations.²⁸³ These boundaries therefore indicate priorities for technological governance. Ozone destroying technologies have been checked by the Montreal protocol, but disruption of the nitrogen and phosphorous cycles is at critical levels, as are extinctions and biodiversity impacted by chemical pollutants, land-clearing and hunting technologies. The Earth's capacity to assimilate 'novel entities' such as heavy metals, nuclear waste, plastics and other chemicals is not yet quantified, but of considerable concern. The effects of greenhouse gas and particulate emissions are also critical. Beyond these indications, there are the emerging technologies that threaten to get out of hand, such as artificial general intelligence and forms of geoengineering, which demand sustainability risk assessment. These issues are more than just prosaic 'environmental concerns'. Contrary to Fukuyama's view, their governance will also require daring, courage, imagination, and idealism:

The end of history will be a very sad time... daring, courage, imagination, and idealism, will be replaced by economic calculation, the endless solving of technical problems, environmental concerns, and the satisfaction of sophisticated consumer demands

– Francis Fukuyama 1989, p. 25

²⁸² The Online Direct Democracy Party in Australia, for example, offers such a citizen direct-vote policy.

²⁸³ Such as the UN High Level Panel on Global Sustainability (2012), Oxfam, the World Wildlife Fund and the UN Environment Program.

Chapter 14. Conclusion: the owl of Minerva

Only in the maturity of reality does the ideal appear as counterpart to the real, apprehends the real world in its substance, and shapes it into an intellectual kingdom. The owl of Minerva takes flight only when the shades of night are gathering – Georg Hegel 2001 [1820], p. 20.

That wisdom's companion is a natural creature, of strength and beauty, that oversees the world from aloft before swooping down in shadow upon its quarry, fits this finale.

Dusk is falling over the industrial age of fossil fuels and the 'limitless frontier'. It gathers over neoliberal market supremacy, which has failed to answer humanity's greatest problem. At the end of this era the planet-changing power of our technological tigers is apparent. After two centuries of technological outburst, we have reached a point where its pattern is clear. Just as modern capitalism cannot control itself, it cannot control the technologies from which it profits; the exponential growth it provokes inevitably leads to material entropy. Unrestrained, it is antipathetic to the planet and to humanity.

Capitalism's handmaiden, innovation, concerns the diffusion of novel technologies. But unlike the owl, innovation does not inevitably augment wisdom. It is blind to the benefit or harm that such dispersal might bring. Rather, innovation worships at the value-free "altar of change" (Vinsel & Russell 2016). As another Russell (1946) said, it is a kind of madness.

Much concern with technology centers on energy and how its emissions lead to global warming and to a cascade of detrimental effects. Geoengineering responses such as atmospheric aerosol spraying, or seeding of the seas with iron, may evoke unforeseen results. Nuclear technologies risk meltdown and spawn the conundrum of waste that cannot be assimilated. Chemical technologies still pollute the waterways despite knowledge of sustainable alternatives. Mining and smelting technologies are not sustainable yet could be much contained and improved. There is risk of pandemic from genetic experimentation. And there is the 'existential threat' of artificial intelligence that uncritically but inexorably follows instructions embedded in its algorithms, written by our alien overlords.

All life is counter-entropic within itself (Schrödinger 1944; Lovelock 1979). The external entropy it necessarily creates can only be offset by incoming energy. The Earth is literally a solar-powered life-support system – for humans and for myriad, but dwindling numbers of other species. That life support system is malfunctioning mainly due to the impact of human technologies. Unless our future is to be degraded and inert, as our sibling moon reminds us of such a fate, our technologies must support life. The imperative is to treat 'our common home' as if we intend to stay – and as if we want other species to stay with us. Technologies that frustrate that imperative must be reined in; technologies that advance it must be encouraged.

This dissertation has approached the conundrum of sustainability by assessing how it is conceived and the contribution of its classic components to human impact upon this planet. While the rate of population increase is at last slowing, such is its momentum that our numbers will probably continue to swell until the end of the century. Rising affluence and consumption, especially of food and energy in the East and South, will place additional strains on primary and extractive industries and demand better ways to fuel and transport within and between settlements. Neither population nor affluence can be braked through policy leverage in the medium term; such methods are simply unpalatable or have unacceptable consequences for those who already have little. In the West, the rising inequality that is intrinsic to capitalism fragments political coherence.

The assertion that technology offers our best chance in the pursuit of sustainability is highly contested. The case studies illustrate major concerns with how it is developed and deployed. Yet if not technology, then what? It is technology that has defined our civilisation. It is evolving rapidly. While it has wrought great harm, it has also brought great benefit. Our relationship with technology has always been interwoven with our historical economic systems; much has centered on the relative price of labour, on slavery, and on the development of labour-saving devices in the West. But the most powerful force in technological development over the period of the Industrial Revolution has been capitalism, often linked with the concerns of the military. Even the present key technology platform, the Internet, has military origins. These two forces are exceptionally difficult to control. Neither recognises limits or end points. Both amplify rivalry, whether of the individual or the nation state. Both are based on continuous development.

The direction of that development may nevertheless be channelled. Now that it is the entire planet that is affected in this Anthropocene, how technologies are governed, demands a global approach. At the same time, such is the diversity and rapid development of new technologies in this digital era, that agility is essential to any form of effective governance. There is no world government, but a world government in an institutional sense may not be warranted – at least as far as reasserting direction and control over technology is concerned – as it would be clumsy. Agility may be attained through a network system that links existing and new stakeholders in a mesh large enough to encompass major global issues, yet fine enough to be sensitive to particular emerging developments and impacts.

In deference to Snow, Pirsig and McLuhan, the need to bridge the quantitative and the qualitative in resolving this conundrum is apparent. Scientists, engineers and technocrats are essential to any move to bend technology in the direction of sustainability. Philosophers, writers, economists and politicians are needed to reform the economic system and the military towards a capacity to accept and benefit from it. Politically, it is well past time to assert leadership over technology, over the economic system and over the military so that the fine arts, love, and capital accumulation are, in the longer term, not for nought and for nothing, but rather for all and everything in the present and the future.

Means of effecting such a future have been discussed in the light of the case study assessments. In summary, they include the following:

Legislative measures that would favour technological sustainability include the establishment of non-human rights and the crime of ecocide, limiting corporate influence over representational politics and amending patent law to support genuine progress. Financial measures include restricting investment in unsustainable technologies and promoting re-investment in sustainable alternatives. Re-nationalisation of electricity grids and public transport are alternatives to neoliberal market failures in these sectors if sustainability is to be a priority.

There is a need for technological threat identification, which links existing institutions and facilitates input from a wide range of stakeholders, including support for whistleblowers. As a source of destructive technologies, the military attracts special scrutiny. To the extent that the military can be re-oriented to non-violent roles, there would tend to be a rebalance towards more sustainable technologies, and perhaps towards a peace during which such organisations might redirect their attention.

The tension between values involving technology and nature concerns nature's intrinsic value as against the practical value of working within altered ecosystems in conjunction with corporate interests. Technoethics commissions may be useful, but the need to regulate data that simultaneously rewards openness, preserves privacy and enables its analysis is more pressing. Sustainability and technology demand an underpinning narrative; one that is both practical and aspirational; as with Dryzek's reformist environmental discourses, both prosaic and imaginative, or as with Steffen's greens and greys, more bright green (innovation and regulation) than the alternatives.

Elements of an effective governance system include transparency involving usable and accessible information, inclusive participation, integrity fortified by a clear sense of mission and a policy capacity drawn from polycentric networks and the encouragement of public input. Such a system would first relate to technologies that affect the Earth system boundaries. A global institution designed as a central focus of governance for technological sustainability would especially encourage network linkages between existing institutions and illuminate areas where progress has been realised. Accountability is ultimately to all of us; its sanction is the quality of our existence.

The governance of technologies for sustainability must itself rely on technologies available for data, information and knowledge, as well as for communication. These technologies are easy to identify and access is at issue. But for wisdom, there is no such technology; ultimately wisdom depends on human judgement. As technological complexity increases, expertise must narrow. Judgement of technological quality then is a series of human overlaps. These connections can be made across and between disciplines, and also across experiences. Neither the blind wisdom of the market nor the omniscience of a central authority can be assumed. To govern technology for sustainability, we must "reach beyond the powers of commerce and command" (Kemp, Parto & Gibson 2005, p. 26) to a shared responsibility that encompasses the Earth.

One key challenge between technology and sustainability is on the one hand against the attitude that our predicament is inevitable and that any effort can only make things worse. It is on the other hand against the promise that technology will solve all problems (Buckup 2016). In either discourse we become passive subjects in a world of increasing uncertainty, whereas awareness, thought and participation is critical if our species is to have a future.

Driven only by national rivalry or by the quest for profit, technology has defined the last two hundred years of human civilisation – at its most triumphant and at its most demeaning. At this gathering of the dusk, unless the quest for sustainability overrides other considerations of technology's governance, a long night looms ahead.

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